TECHNOLOGY DEPARTMENT

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by L. W. JOHNSON, M.Met., M.I.Mech.E., M.I.P.E.

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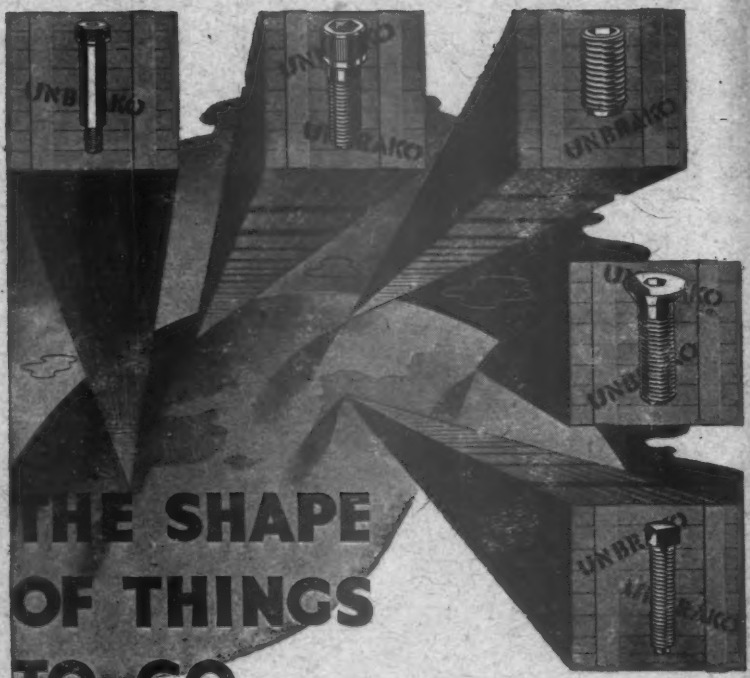

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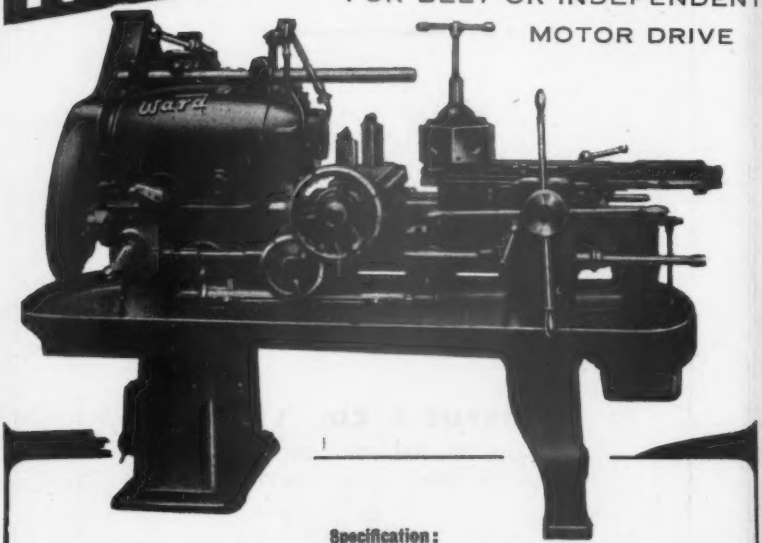

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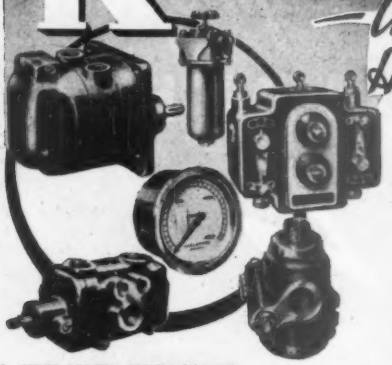

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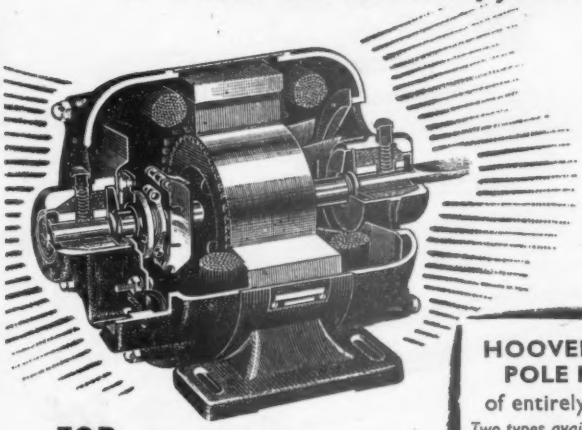

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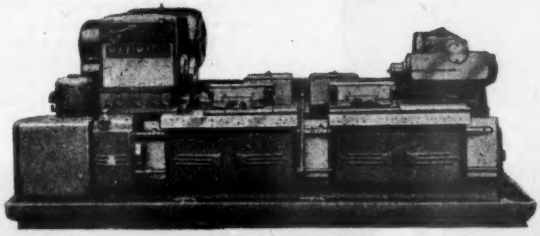

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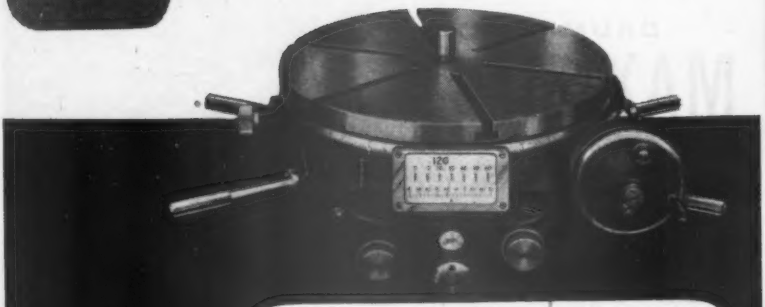

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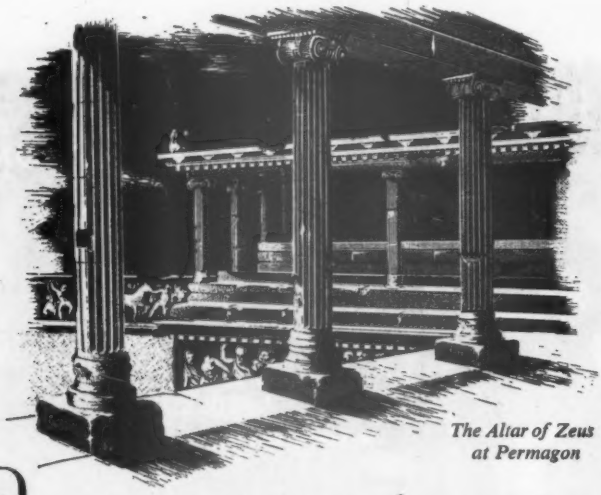

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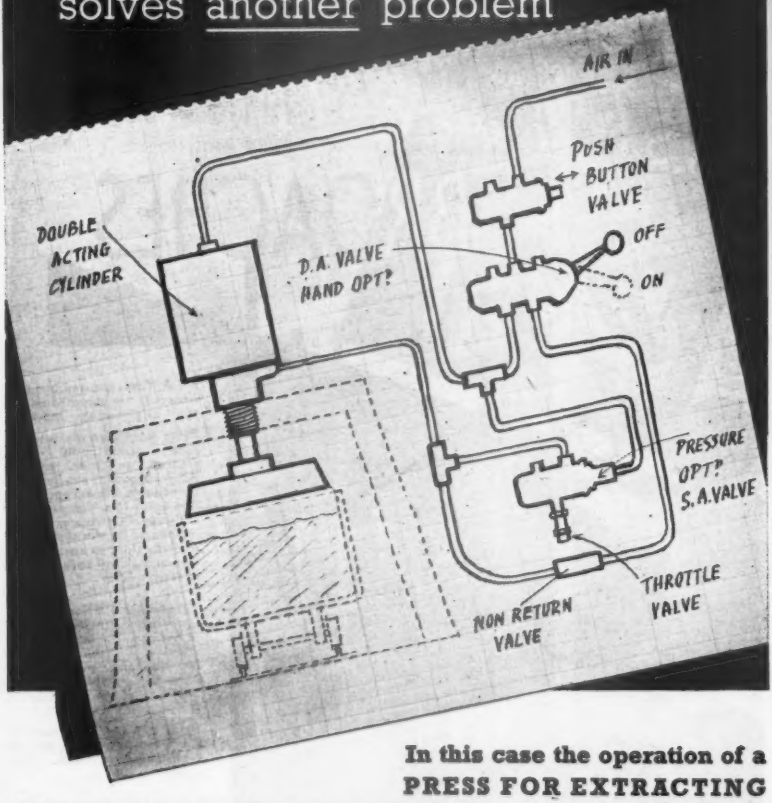

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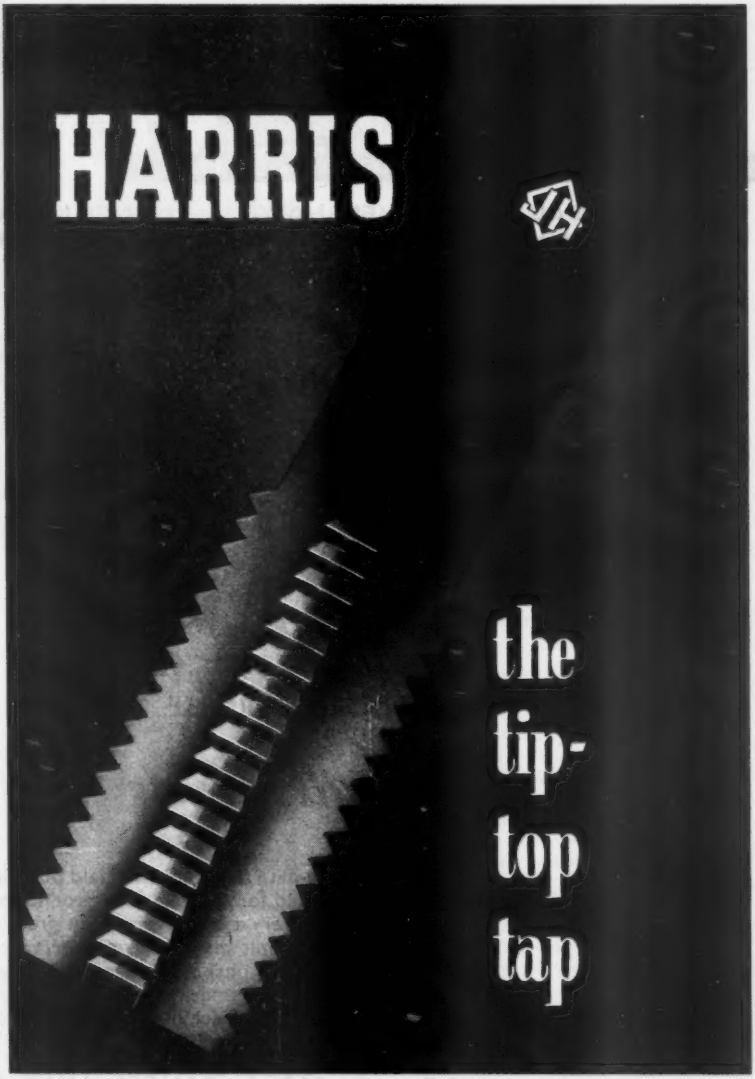

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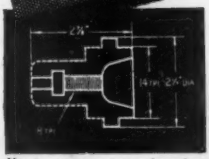

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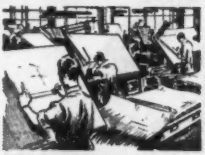

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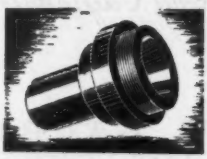

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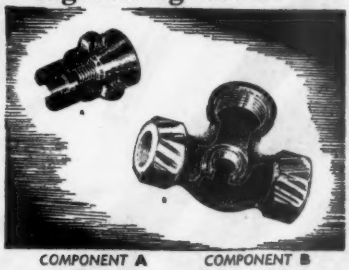

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SIR LIONEL KEARNS, C.B.E., B.A., M.I.P.E.

Henry Ward Lionel Kearns, Chairman and Managing Director of H. W. Kearns and Company, Ltd., Broadheath, Manchester, and Director of Bromilow and Edwards, Ltd., Bolton, is one of the outstanding figures in the machine tool industry. Between 1941 and 1945 he was elected first, Vice-President, and subsequently President of the Machine Tool Trades Association.

He also played a leading part in the formation of the Production Engineering Research Association of Great Britain. In accordance with the constitution of that body, its Chairman has to be nominated by the Institution of Production Engineers for the first five years of its legal existence. As this national organisation owes its origin to the initiative and enterprise of the Institution, members should be proud of the fact that the success of this venture is largely due to Sir Lionel's skilful guidance.

In addition to being Chairman of its Council, he also presides over its Executive Committee, and furthermore, is a member of the newly constituted Research Committee of the Institution of Production Engineers.

The youngest son of the late Henry Ward Kearns, B.Sc., J.P. of Cheshire, Sir Lionel was educated at Rugby and Christ's College, Cambridge, where he took his B.A. in Engineering, in 1912. After spending two years with Vickers, Ltd., Barrow-in-Furness, he joined the Royal Artillery and served with the rank of Captain throughout the First World War, during which he was mentioned in despatches and awarded the Belgian Croix de Guerre. In 1919 he became Joint Managing Director of H. W. Kearns and Company Ltd., and in 1933, Chair nan and Managing Director.

He has held various important appointments in the Ministry of Supply and in the course of his duties has travelled extensively in India, Australia, New Zealand and South Africa. He was Chairman of the Eastern Group Requirements Committee, 1942 to 1945, and Director-General, Production Services, from 1945 to 1946. He is at present a member of the Machine Tool Advisory Council of the Ministry of Supply.

In 1941, he was awarded the C.B.E. and knighted by H.M. The King in 1946 for his outstanding services in connection with supply problems during the Second World War.

INSTITUTION NOTES

December, 1948

COUNCIL MEETING The next meeting of Council will be held on January 20th, 1949, at 36, Portman Square, London, W.1, at 11 a.m.

SECOND INTERNATIONAL CONGRESS The British Committee of the World Engineering Conference announces that the Second International Congress will be held in Cairo, at the invitation of the Egyptian Government, from 20th-26th March, 1949.

The Congress is being organised by the World Engineering Conference, a permanent organisation comprising some 1,200 engineers and technicians representing the technical institutions of thirty nations, who attended the First International Technical Congress held in Paris in September, 1946.

The theme and title of the Congress will be " Raw Materials as an Industrial and Social Problem " and full particulars may be obtained from the Organising Secretary for Great Britain, Mr. Robert Lowe, M.S.C., M.J.I.E., 82, Victoria Street, London, S.W.1.

ISSUE OF JOURNAL TO NEW MEMBERS Owing to the fact that output has to be adjusted to meet requirements, and in order to avoid carrying heavy stocks, it has been decided that the Journal will only be issued to new Members from the date they join the Institution.

IMPORTANT In order that the Journal may be despatched on time, it is essential that copy should reach the Head Office of the Institution not later than 40 days prior to the date of issue, which is the first of each month.

BOOKS RECEIVED " Metal Cutting Tools " by P. S. Houghton. Chapman & Hall. Price 25/- net.

This book covers the wide range of metal cutting tools available to engineers today. Some ten chapters appear at first sight to be largely a catalogue of small tools, including hand files and scrapers, but even here perusal of the brief accompanying text will indicate the author's thorough understanding of his subject and show that this section should not be lightly disregarded even by the more experienced reader.

Other chapters are devoted to gear and spline hobs, broaches, carbon, alloy and high-speed steels, and their heat treatment,

stellite, carbide and diamond tools. Tool and cutter grinding receive attention, also coolants, grinding wheels, cutting speeds and feeds and negative rake cutting. The book concludes with a chapter on the horsepower required for various metal cutting operations.

The volume is well produced and the illustrations very clear. The text is brief and to the point. The large proportion of space given to the illustrations appears to have prescribed a limit to the text and prevented the author from extending himself on some of his subjects.

A.A.F., M.I.P.E.

" Rubber to Metal Bonding " by S. Buchan. Crosby Lockwood & Son, Ltd. Price 21/- net.

This is the authoritative book on the technical process.

B.W.M.W., A.M.I.P.E.

" Ferrous Metals for the Engineer " (Industrial Text-book Series, No. 14) by Reginald Fox, A.Met.(Sheff.)., A.I.M. Charles Griffin & Co. Ltd. Price 12/6 net.

" Powder Metallurgy in Practice " ; " Press Die Design and Construction ", Parts I and II. Machinery Publishing Co. Price 3/6 net each.

" Non-Ferrous Metals and Alloys " by Edwin Gregory and Eric N. Simons. Paul Elek Publishers Ltd. Price 12/6 net.

" Engineering Optics " by Habell and Cox. Sir Isaac Pitman & Sons, Ltd. Price 35/- net.

NEWS OF MEMBERS

Mr. W. G. Aldred, A.M.I.P.E., has been appointed General Manager of Messrs. Herbert Alexander & Co. Ltd., Leeds.

Commander (E) L. Baker, R.N. (ret.), A.M.I.P.E., has taken the position of Superintendent Engineer of Alfred Holt & Co. Ltd.

Mr. V. N. Butler, A.M.I.P.E., A.R.Ae.S., has taken an appointment as Personal/Technical Assistant to the Managing Director of Omes Ltd., Barnes.

Mr. V. H. Carr, A.M.I.P.E., is now Works Manager of Zenith Carburettor Co. Ltd., Stanmore.

Mr. C. L. Cook, A.M.I.P.E., is now Lecturer in Production Engineering at the County Technical College, Guildford.

Mr. A. A. S. Dickson, B.Sc., A.M.I.P.E., A.M.I.Mech.E., is now Assistant Works Manager with Shaw Glasgow, Ltd., Glasgow.

Commander (E) S. Dickinson, R.N., O.B.E., A.M.I.P.E., has been appointed Head of the Department of Engineering and Mining at the City of Wakefield Technical College.

Mr. A. Flindle, A.M.I.P.E., is now Manager of the Turbine Department, Daniel Adamson & Co. Ltd., Dukinfield.

Mr. R. E. Green, Int.A.M.I.P.E., is now Works Manager of Berkel & Parnall's Slicing Machine Mfg. Co. Ltd., Enfield.

Mr. E. G. Hudson, A.M.I.P.E., has been appointed a Director of Catey & Martyn, Ltd., Cornwall.

Mr. E. J. H. Jones, M.B.E., M.I.P.E., Member of Council, has been appointed to the Board of A.E.C. Ltd., Southall.

Mr. F. P. Laurens, O.B.E., M.I.P.E., has been appointed a Director of Powers-Samas Accounting Machines, Ltd., and General Manager at the Croydon Works.

Mr. W. P. Macmillan, A.M.I.P.E., is now Works Manager of Jason Industries, Ltd., Welshpool, Perth, W. Australia.

Mr. C. L. McCombie, Int.A.M.I.P.E., is now Chief Engineer with Riddell Cousland & Co. Ltd., Glasgow.

Mr. G. Murray, M.I.P.E., formerly Managing Director and Founder of G.P.A. Tools & Gauges, Ltd., Manchester, has now taken over Bond & Partners, Consulting Engineers & Agents, Newcastle-on-Tyne.

Mr. W. D. Opher, M.I.P.E., M.I.Mech.E., has been appointed Works Superintendent at the Crayford Works of Vickers-Armstrong, Ltd.

Mr. H. Probyn, A.M.I.P.E., is now an Industrial Consultant with Personnel Administration, London.

Mr. F. A. Rose, A.M.I.P.E., is now Chief Planning and Methods Engineer with British Electric Meters, Ltd., Bangor.

Mr. G. F. Shrigley, M.I.P.E., has been appointed Director and General Manager of the British Light Steel Pressings, Ltd., Acton.

Mr. L. R. Smith, A.M.I.P.E., is now Chief Draughtsman of the English Electric Co. (of Canada) Ltd., Ontario.

Mr. W. G. Tinslie, A.M.I.P.E., is now lecturer in Mechanical and Production Engineering at the Royal Technical College, Glasgow.

Mr. W. J. J. Tucker, Int.A.M.I.P.E., is now Lecturer in Engineering at Wandsworth Technical College.

Mr. C. J. Uridge, Grad.I.P.E., has joined Railway & Power Engineering Corporation, Ltd., Toronto, as Planning Engineer.

Mr. R. R. Watkins, Int.A.M.I.P.E., is now Senior Mechanical Engineer with the Spruce Falls Power & Paper Co. Ltd., Kapuskasing, Ontario.

Mr. F. Wilson, A.M.I.P.E., is now Senior Assistant in Production Engineering at the Technical College, Burton-upon-Trent.

OBITUARY The Institution deeply regrets to announce the deaths of the following members : Mr. A. J. Hitch, A.M.I.P.E., Mr. N. Midgley, A.M.I.P.E., Mr. J. R. Woodall, Grad.I.P.E., Mr. A. McNab, A.M.I.P.E.

SECTION MEETINGS

The following meetings have been arranged to take place in December, 1948. Where full details are not given, these have not been received at the time of going to press.

December

1st LIVERPOOL SECTION. An Informal Discussion has been arranged for Members only. It will be held at the Exchange Hotel, Liverpool, at 7.15 p.m.

1st NOTTINGHAM SECTION. A lecture has been arranged on " Internal Transport." It will be given at the Victoria Station Hotel, Nottingham, at 7 p.m.

1st PRESTON SECTION. A lecture on " The Commercial Possibilities of the Lost Wax Process " will be given by Mr. A. Short, A.M.I.P.E., at Clayton Goodfellow & Co. Ltd., Blackburn.

1st WOLVERHAMPTON SECTION. A lecture on " Production Research & Development in America " will be given by Dr. H. Orenstein, M.I.P.E., M.I.Mech.E., at the Dudley & Staffs. Technical College, Wolverhampton.

3rd WEST WALES SUB-SECTION. A visit to the Metal Box Company, Neath has been arranged and a lecture on " Can Making Machinery " with a discussion will be given by Mr. R. R. M. Quarry, M.A., at the Metal Box Company Works, Neath, at 7.30 p.m.

6th YORKSHIRE SECTION. A lecture has been arranged on the " Education of the Production Engineer." It will be given by Mr. T. B. Worth, A.M.I.Mech.E., M.I.P.E., A.M.I.E.E., at the Hotel Metropole, Leeds.

7th WOLVERHAMPTON GRADUATE SECTION. A lecture on " Electronics in Industry " will be given by Mr. S. Jefferson, Telecommunication Research Establishment (M. of S.), at the Willenhall Evening Institute, at 7.15 p.m.

8th SHEFFIELD SECTION. A lecture on " The Education of the Production Engineer " will be given by Mr. T. B. Worth, A.M.I.Mech.E., M.I.P.E., A.M.I.E.E., at the Royal Victoria Station Hotel, Sheffield, at 6.30 p.m.

8th BIRMINGHAM SECTION. A Christmas Party and Dance has been arranged and will be given at the Grand Hotel, Birmingham.

December—*cont.*

8th LUTON GRADUATE SECTION. A lecture on "Drop Forging" will be given by Mr. H. M. H. Fox at the Midland Hotel, Luton, at 7.30 p.m.

8th EDINBURGH SECTION. A lecture on "Selection and Application of Sand in Foundries" will be given by Mr. W. E. W. Dent, B.Sc., A.I.M., at the North British Station Hotel, Edinburgh, at 7.30 p.m.

9th LONDON SECTION. A lecture on "Some Important Aspects of the Industrial Employment of the Blind" will be given by D. R. Fusch, Ph.D.(Vienna), B.A.(London), at the Assembly Hall, Royal Empire Society, Northumberland Avenue, W.C.2 (Craven Street entrance), at 7 p.m.

9th CORNISH SECTION. A lecture on "Fabrication Design as a Substitute for Casting" will be given by Mr. F. G. Rout.

10th WESTERN SECTION. The Ninth Annual Dinner will be held at Hawthornes Hotel, Clifton.

10th EASTERN COUNTIES SECTION. A lecture on "Material Handling" will be given by Mr. Hartford M. King at the Britannia Works, Colchester, at 7.30 p.m.

10th COVENTRY SECTION. A lecture on "New Developments in Centreless Grinding" will be given by Mr. A. Scrivener, M.C., in the Greyfriars Room, Geisha Cafe, Coventry, at 7 p.m.

13th HALIFAX SECTION. A lecture on "Production and Inspection of Gears" will be given by Mr. J. Milwain, M.I.P.E., at the White Swan Hotel, Halifax, at 7 p.m.

14th BIRMINGHAM GRADUATE SECTION. A lecture on "Air Operated Fixtures" will be given by Mr. N. P. Watts at the James Watt Memorial Institute, Great Charles Street, Birmingham, at 7 p.m.

14th COVENTRY GRADUATE SECTION. A lecture will be given on the "Production of Aluminium Houses" by T. E. Marriott in Room A.5, Technical College, Coventry, at 7.15 p.m.

15th LIVERPOOL SECTION. A lecture on "Manufacture and Application of Sintered Carbides" will be given by Mr. H. Eckersley, M.I.P.E., and supported with a film "The Wimet Age." It will be held at Radiant House, Bold Street, Liverpool, at 7.15 p.m.

15th BIRMINGHAM SECTION. A lecture on "Costing as an Aid to Management" will be given by Mr. H. H. Norcross, F.C.W.A., F.I.I.A., A.I.P.E., at the James Watt Memorial Institute, Great Charles Street, Birmingham, at 7 p.m.

December—*cont.*

16th GLASGOW SECTION. A lecture on "Furniture Production" will be given by Mr. R. E. Harrison, at the Institution of Engineers & Ship Builders in Scotland, 39, Elmbank Crescent, Glasgow, at 7.30 p.m.

16th LEICESTER SECTION. A lecture will be given on "Education for Management" by Lt.-Col. L. Urwick, O.B.E., M.C., M.A., M.I.P.E., in Room 104, Leicester College of Technology, The Newarkes, Leicester.

17th WOLVERHAMPTON GRADUATE SECTION. A lecture on "Electronics in Industry" will be given by Mr. S. Jefferson, (Telecommunication Research Establishment, M. of S.), at the Wolverhampton & Staffs Technical College at 7.15 p.m.

17th NORTH-EASTERN GRADUATE SECTION. A film evening will be held at Neville Hall, Newcastle-on-Tyne, at 6.30 p.m.

20th HALIFAX GRADUATE SECTION. A lecture will be given on "The Manufacture of Plants used in the Production of Town's Gas" by Mr. W. Raistrick at the Technical College, Halifax, at 7 p.m.

20th MANCHESTER SECTION. A lecture will be given on "Development and Application of all Branches of Resistance Welding" by Mr. C. A. Burton at the Manchester College of Technology, at 7.15 p.m.

22nd DERBY SUB-SECTION. A lecture on "Centreless Grinding" will be given by Mr. H. M. Goodwin at the Art School, Green Lane, Derby, at 7 p.m.

28th LUTON SECTION. A lecture will be given on "Methods of Achieving Greater Output per Square Foot" by Mr. A. Smart, Grad.I.P.E.

SECTION ACTIVITIES

BIRMINGHAM The 1948/49 Session opened on 15th September with a lecture by Dr. J. D. Jevons, B.Sc., F.R.I.C., F.I.M., on "Difficulties and Developments in Deep Drawing and Pressing." The James Watt Memorial Hall was filled to capacity and a very comprehensive discussion followed the paper. The Section Committee is arranging to stimulate interest in the Institution among local industrial executives, by giving wider publicity to the Section's technical activities. The local Technical Colleges and industrial organisations will be kept fully informed of all lectures and works visits.

A special meeting was held on Wednesday, 29th September when Lt.-Col. L. Urwick, O.B.E., M.C., M.I.P.E. gave an address on "Education for Management." A feature of this meeting was the invitation of many senior industrial executives in order that they may become fully aware of the work of the Institution. The interest shown in this address was evidenced by the fact that 600 applications for the 350 seats available were received by 15th September.

The Section continues to play an active part in the work of the Midland Advisory Council on Productivity. Two members of the Section have been recently appointed to a Sub-Committee of the Council, dealing with its first investigations.

The October lecture on Wednesday, 20th October, concerned "The Lost Wax Process in Precision Casting" by Mr. A. Short, A.M.I.P.E. On 10th November, a party of members visited the Rugby works of the British Thomson-Houston Company Ltd.

The first social event of the Session was the Graduate Section Dance at the Crown & Cushion Hotel, Perry Barr, on Saturday, 2nd October.

BIRMINGHAM GRADUATE

This quarter has been a very quiet one for all members. The hoped-for cricket match against the Birmingham Section could not take place due to bad weather and lack of ground.

The 1948/49 session started with a film display by the Carborundum Co. Ltd., and had a total attendance of 70, about half being Student and Graduate Members. The Committee extends a cordial welcome to all new members and also to lady visitors, whom they will be pleased to see at all functions.

CALCUTTA

Two meetings have been held, both of which were well attended. The first, which took place on 18th March, comprised two films, "Operation Tynemouth" and "The Story of Formica." Mr. Gordon Fischel was present, and answered questions during the subsequent discussion on the qualities of various types of plastics.

On 21st April, Mr. H. R. Badyal gave an excellent and well-prepared paper on "Meehanite Metal as a Constructional Material," to a large and appreciative audience.

Membership is steadily increasing, and the number of applications now makes it necessary to hold Membership Sub-Committee meetings every month. It is gratifying to report that a number of students and graduates are coming forward.

The Section is endeavouring to go ahead with a scheme proposed by London regarding Production Engineering Courses, but it should be appreciated that a great deal of work will have to be done before this can be put into effect. One of the chief difficulties is to determine where to hold them, and also there is the question of teachers.

The payment of subscriptions and entrance fees into the Calcutta Section has now been approved, and it is hoped to appoint an Hon. Treasurer shortly. This will be a great help to certain people who find it difficult to remit money to the U.K.

It is possible that another Section will be started in Bombay. This will tend to increase our membership still further and add to the progress of the Institution in this country.

During the forthcoming session it is hoped to hold meetings each month between November and April.

CORNWALL

Since its last report in March, this Section has elected its new President, and has admitted new members; there have also been a number of transfers to higher grades of membership.

The death of the Section's Founder Member, Mr. J. G. Young, was a great blow, as great help had been received from him in many directions.

A lecture on "Atomic Power" by Col. Mirehouse, M.B.E. was arranged for 14th October, followed by a lecture on "Cast Iron," by Dr. H. T. Angus, M.Sc., on 11th November. The lecture in April will be given by Mr. Hartford King, on "Mechanical Handling," and it is hoped to arrange papers for three remaining dates in the intervening months.

COVENTRY GRADUATE

The Coventry Graduate season opened with a lecture on "Single and Multi-Spindle Automatic Machines" by the Graduate Section's Chairman, Mr. R. F. Eaton. The lecture was well supported and was illustrated by a number of slides. A good discussion followed.

On 5th October, Mr. H. M. H. Fox, M.I.P.E., gave a lecture on "An Outline of Die Forging Practice."

The Committee has held several meetings to make the necessary arrangements for the lecture programme.

DERBY

After the summer recess this sub-section has settled down to an interesting programme of lectures to be given during the winter session. All details of meetings have been finalised, and with the exception of two lectures, all papers to be read deal with a specific production engineering subject.

The first meeting was held on 20th September and took the form of an illustrated talk by Dr. D. F. Galloway, M.I.P.E., on "The Activities of the Production Engineering Research Association of Great Britain."

EASTERN COUNTIES

The lecture programme for 1948/9 opened on 15th October with a lecture by the Education Officer, Mr. T. B. Worth, on the "Education of the Production Engineer." Every effort is being made to interest all local

engineers in this subject, and also to attract senior students of the Ipswich School of Technology.

Many applications for membership have been received during the past quarter, the number being well above the average.

We regret to report that Mr. D. Braid, M.I.P.E., and Mr. R. E. Dunnett, M.I.P.E., have found it necessary to resign from the Committee on leaving this town for business reasons. Both these members have made a valuable contribution to the development of the Eastern Counties Section. The Section also suffered a great loss during the quarter in the death of Mr. H. A. Hartley, who was a Founder Member of this Section, a Past President, and for many years a member of the Committee.

During the summer months, conferences have been held with kindred local Institutions with a view to holding occasional joint meetings, where the subject matter has a common interest.

EDINBURGH

On 9th June, 1948, the Committee visited Smith's Clock Factory at Carfin, at the invitation of Mr. Desmond, and spent a most interesting and instructive afternoon. It was a novel experience for most of the Committee members to inspect a factory which is devoted entirely to the manufacture of one product, and to see the high degree of specialisation which is possible under these conditions.

No lectures or meetings were held during the holiday season, but an interesting programme has been arranged for the ensuing session, in which a team of seven well-known lecturers will take part. The November meeting was a joint affair with the East of Scotland Branch of the Institute of Personnel Management, at which Miss Anne Shaw, M.A., M.I.P.E., lectured on " Motion Study." The season opened with a lecture by Mr. W. C. Puckey, M.I.P.E., F.I.I.A., on " The Gap between the Production Engineer and the Manager," and other speakers will be Mr. W. E. W. Dent, B.Sc., A.I.M. (" Selection and Application of Sand in Foundries ") ; Mr. Lewis C. Ord (" Britain's Industrial Future ") ; Mr. T. B. Worth, A.M.I.Mech.E., A.M.I.E.E., M.I.P.E., (" The Education of The Production Engineer ") ' Mr. F. T. Barwell (" Plastics in Engineering ") ; Mr. P. H. Briggs, B.Sc. (" Electronics in Industry.")

GLASGOW

During the summer, three works visits have been held, to Messrs. Hoovers (Electric Motors) Ltd., Cambuslang ; Messrs. G. & J. Weir, Ltd., Cathcart, Glasgow, and Messrs. Anderson Boyes Ltd., Motherwell. These visits are popular with many members, and it is hoped that it will be possible to make them a permanent feature of our programme.

In the winter programme, a number of lectures of particular interest from the managerial side have been arranged, to stimulate this branch of the Institution's activities. On the educational side,

Mr. Worth will give his paper on " The Education of the Production Engineer," which will be followed later by a visit to the Royal Technical College, Glasgow, to have an Informal Discussion on " Developments in Production Engineering Education," when the college authorities will explain and show the various facilities which they are now providing.

HALIFAX

A number of members and friends visited the School of Military Engineering, Ripon, on 26th June, when an inspection was made of the Plant, Roads and Airfields School, and Fieldworks and Bridging School. This was a most interesting and successful day, and appreciation was expressed to the authorities for the splendid arrangements made on our behalf.

The winter session opened on Monday, 4th October, with an informal Discussion Evening, when the subject was " The Position of the Production Engineer in relation to the National Economy." A varied programme of lectures will be continued throughout the winter months, the concluding meeting being in April 1949. The Annual Dinner Dance was held at the Alexandra Cafe, Halifax, on Thursday, 18th November.

Applications for membership and for transfer to higher grades are steadily coming in, and a special drive is being made to meet the desirability of an increase in top grade membership.

HALIFAX GRADUATE

The annual long-distance Works Visit to Messrs. Cammell Laird & Co. Ltd., Birkenhead on 5th June has been the only activity this quarter. A party of 37 members and friends spent a very interesting and entertaining day. They saw numerous types of ships in various stages of construction, and a submarine in one of the dry docks aroused great interest. Other departments visited included Joiners, Pattern-makers, Machine Shop, Engine and Turbine Fitting, Plating, Fitting-Out Basin and Dry Docks. The Section would like to record its appreciation of the splendid arrangements for this visit made by Mr. N. Jackson, last year's Section Hon. Secretary.

LEICESTER

The activities of this Section were confined to action by the Committee, who have prepared a vigorous and interesting programme for the Winter Session 1948/9. An interesting and pleasant day was experienced by the members who took part in a visit to London on 11th September, to attend the Machine Tool and Engineering Exhibition at Olympia ; this was followed by an evening's entertainment at the Adelphi. Preliminary arrangements have been made for a Dance to be held early in 1949.

The Section was honoured at its first meeting this year by a visit from Major C. B. Thorne, M.C., Director and General Secretary,

and Mr. T. B. Worth, Education Officer. Major Thorne spoke on "The Growth of the Institution and its Place in the Industrial Life of the Nation," and Mr. Worth on "Some Aspects of Technical Education for Production." Both of these subjects are of vital importance at the present time. Earlier in the day, visits were made to three large industrial concerns in the city, with a view to establishing closer liaison between Institution representatives and local industry. Many prominent individuals, representing both Industry and Education, together with members of kindred Institutions, attended.

The Committee has carried out an intensive drive to attract more senior and qualified individuals to membership of the Institution, and the results have been reflected in the satisfactory number of applications which have been reviewed.

LIVERPOOL

The outstanding event since the last report was the Dinner inaugurating the first session in Liverpool under full Section status. This was attended by 110 members and friends and was an outstanding success. The chief guest, the Rt. Hon. J. Harold Wilson, P.C., M.P., President of the Board of Trade, was supported by notables in the city's civic life; prominent Merseyside industrialists; Regional Controllers of various Government Departments, and several guests from other Sections of the Institution including Mr. J. D. Scaife, a former President of the Institution; the President of the Yorkshire Section, the President and Hon. Secretary of the Preston Section and the Director & General Secretary, Major C. B. Thorne, M.C. The quality of the speeches was of a high standard and of great interest.

A particularly significant announcement was made by the Director of Education for the City, that steps are in hand for setting up courses leading to the Higher National Certificate in Production Engineering. This was greeted with acclamation.

Membership now totals 125.

LONDON

A programme of eight lectures has been arranged covering a variety of subjects, including management, and a joint meeting with the Institute of Plastics. The meetings will be held in the Assembly Hall of the Royal Empire Society, and light refreshments will be available from 6.30 p.m. This hall proved to be very popular with members last season.

The Section was fortunate in having Mr. C. B. Colston, C.B.E., M.C., D.C.M., to give the first lecture of the session, "The Position of the Production Engineer in Relation to the National Economy"—the Institution's Common Subject for the year.

Initial steps have been taken to start the Reading Sub-Section, but this can only be successful if interested members give their

active support. Those interested should communicate with Mr. F. V. Waller, A.M.I.P.E., Miles Aircraft Ltd., The Aerodrome, Reading, or the London Section Hon. Secretary.

There has been a steady flow of new applications for membership during the summer.

LONDON GRADUATE

Members of the Section visited the Machine Tool Exhibition at Olympia on 25th August.

The first meeting of the Session was held on 21st September, when Mr. Cyril Dee and Mr. F. E. Maer, M.I.P.E. lectured on "Joint Consultation." Mr. Dee outlined the history of Joint Consultation at factory, regional and national level from the beginning of the First World War up to the present day, and gave some very interesting information which indicated future trends. Mr. Maer then stated his reasons for supporting Joint Consultation and described the technique which he considered most suitable for engineering factories. Several members of the Senior Section attended, together with the Director and General Secretary, who made several contributions to the very lively discussion which followed the lecture.

LUTON

The Section commenced the new session with an address by Sir Charles Bartlett, M.I.P.E. on the "Position of the Production Engineer in Relation to National Economy." This address linked up the following three papers which dealt with the same theme from varying aspects.

On 16th September a large party of members and friends visited the works of Enfield Cables Ltd. and had an instructive tour through the various stages of cable manufacture.

The Graduate Section has also completed arrangements for the winter session and start the programme with a colour film on Steel.

MANCHESTER

The Syllabus Sub-Committee has arranged a very interesting and varied programme of lectures for the coming session. Arrangements have been made to revert to Monday evenings, as pre-war, for our meetings, instead of the Wednesday fixtures which were arranged to meet the wartime requirements of the Manchester College of Technology.

At the opening meeting on 27th September, Dr. H. Orenstein, M.I.P.E. gave an extremely interesting talk on "Production Research and Development in America" to a very large audience. The next meeting, in October, took the form of a report on the Machine Tool Exhibition at Olympia by Mr. Hubert Bentley, of "Machinery."

A Dinner and Social Evening was arranged for 8th October, and it is hoped that this will be the forerunner of other social evenings during the coming winter. Visits have also been arranged to various industries in this area and these should prove to be popular with members.

MANCHESTER GRADUATE A visit on Saturday, 12th June to Messrs. Mitchell, Shackleton & Co. Ltd., Crankshaft Forging Specialists, proved very interesting in spite of the fact that due to operating on a forty-hour week, the plant was not in full production.

Mr. R. Cleary, Grad.I.P.E. who was elected to succeed Mr. E. Evans, Grad.I.P.E. as Section Chairman, took over his duties at the first Committee Meeting of the current session on 7th September.

On 13th September, Mr. A. Short, A.M.I.P.E. of Derby Sub-Section, gave an informal lecture on "The Lost Wax Process." The paper on this relatively recent process was very interesting. Five lectures will be presented at the College of Technology during the current session, and the Committee hope to arrange Works Visits once a month.

MELBOURNE At the May meeting an interesting paper was delivered by Mr. F. I. Down, B.Met.E., on "The Performance of Metal Cutting Tools." In June, a lecture was given by Mr. G. A. Alexander, A.M.I.P.E., on "Human Factors in Production Engineering." The speaker, who is a lecturer at the Melbourne Technical College on Industrial Management, treated this controversial subject in an able and lucid manner, and expressed concern at the tendency to technical training in the minutest detail in material things, whilst neglecting the study of the human factor and applied psychology.

Mr. E. J. W. Herbert, M.I.P.E., gave a paper in July on "Diesel Engine Production." which was one of the best illustrated to be presented to this Section. The historical data associated with the development of marine diesel manufacture in this country was extremely enlightening. Other lectures during this session were given by Mr. P. E. A. Frye, A.M.I.P.E., on "Production and Testing of Horizontal Boring Machines," and by Lt.-Col. J. Wrigglesworth on "Drawing Office Practice in Relation to Interchangeable Components."

NORTH-EASTERN The new session had a very successful opening with an excellent attendance for a paper given by a member of this Section, Mr. J. Henderson, M.I.P.E., on "Modern Milling Practice." The paper and slides were excellently prepared from very practical examples and aroused considerable interest.

The retiring President, Sir Claude Gibb, introduced to the meeting his successor, Mr. A. J. Bowron, M.I.P.E. The Section expressed their sincere appreciation of Sir Claude's services and look forward to his valuable guidance in the future.

NORTH-EASTERN GRADUATE

There was no meeting of the Section during the summer season. The newly elected Committee met for the first time on 19th August, to discuss the final details of the winter programme.

Two additional members were co-opted to bring the Committee up to full strength, and a new Vice-Chairman was elected. A programme of four lectures, two visits and a film evening was then approved.

The Section continues to grow in numbers, membership having increased by more than 30% in the last year.

The new Session started on Friday, 17th September, when the Chairman read his address, covering the history of the Institution and particularly of this Section.

NOTTINGHAM

During the summer months, two Works Visits have taken place. The first was to the Royal Ordnance Factory, Nottingham, and was attended by approximately 50 members. Here machines which had been used for the manufacture of implements of war were now producing equipment for peace. The second visit was to the Works of the Standard Motor Company, Coventry, where about 40 members inspected the manufacture of the " Ferguson " tractor. The party was met by Mr. Ellerby, President of the Coventry Section, who had the opportunity of exchanging views with the Nottingham members present. Both visits were extremely interesting, and tribute is paid to the respective managements for their generous hospitality.

The first meeting of the new Session was held on 20th October when the Institute of Industrial Administration joined the Section to hear Mr. E. C. Gordon England, M.I.P.E. talk on " Valid Incentives."

PRESTON

During the summer, members had a very successful visit to Messrs. Courtaulds Ltd., Engineering Works at Clayton-le-Moors. The party was met by the Labour Manager, Mr. Dinnis, and after a very instructive tour of the Works, were entertained to a meal.

On Thursday, 16th September, the Section was honoured by a visit from the Education Officer, Mr. T. B. Worth. Mr. Worth met several members of the Committee together with Dr. Rifkin, Dr. Tyler and Mr. Swan, Heads of Burnley, Blackburn and Accrington Technical Colleges respectively; Mr. Vaughan, Education Officer of Messrs. Howard & Bullough, Accrington; and Mr. Pilkington, Education Officer of Leyland Motors Ltd. A very interesting meeting included the passing of a resolution that Preston Section should ask Headquarters to arrange for a full area meeting, possibly a full day Convention, some time in the spring, to give all the Principals of the Technical Colleges, Works Apprentice Training chiefs and

the industrial leaders of the area an opportunity of discussing all the steps that can be taken to improve liaison between the Technical Colleges, Industry and the Institution of Production Engineers.

The President, accompanied by the Secretary and other members of the Committee, attended the first National Convention in Bournemouth, and wish to express their great satisfaction with the arrangements made by Headquarters. It is felt that the journey was well worth while and the Committee all hope to attend the next Annual Convention.

SHEFFIELD

In view of the outstanding importance of steel production at the present time, the first meeting of the 1948/49 session was of great interest to the Institution. The paper, "Steel Production—Some Facts and Problems" was given by Mr. L. Chapman, and the meeting was attended by a large number of members and friends, including the Managing Directors of most of the leading companies producing high quality steels. At the close of the paper, the speaker was congratulated by the Master Cutler, Col. J. P. Hunt, and Lord Riverdale.

The meeting was followed by a dinner in honour of the prominent industrialists present. The guests also included Mr. C. L. Old, newly-appointed Head of Rotherham Technical College, and Mr. A. Bainbridge, a Past President of the Wolverhampton Section of the Institution.

SHREWSBURY

A very successful lecture meeting was held at Shrewsbury Technical College on 29th September, when a lecture on "Materials Handling Machinery" was given by Mr. A. A. Simpson, A.M.I.P.E.

A Sub-Section Committee meeting was held on September 22nd, during which the future consolidation of the Sub-Section was thoroughly discussed.

SOUTH AFRICA

Approximately 25 members and guests were present at the July meeting at which Mr. H. A. Godwin delivered a paper entitled "Metallurgy of Iron and Steel," covering such aspects of the subject as spectro-analysis of iron and steel, micrography, etc.

The August meeting took the form of a Combined Meeting with the Engineers' Association (S.A.) and was held in the main Lecture Theatre of the Witwatersrand University, Johannesburg. Some 75 members of the two organisations were present to hear Dr. A. Rowe and Mr. H. Sichel deliver a joint address on the subject of "Inspection and Statistical Quality Control."

During September two meetings were held, at the first of which Mrs. N. Lester delivered a paper on "Personnel Management and its Relation to Production Engineering." This was followed by a film meeting.

In October, members attended an organised visit to the Vanderbijl Engineering Corporation, one of the largest engineering firms in South Africa. It is hoped in the near future to arrange for similar visits to other places of technical interest.

SYDNEY

During the present session the meetings have been well attended, and in September about 60 members and friends listened to an interesting address by Mr. N. Shepherd entitled "Some Aspects of Drop Forging" which was well illustrated by slides. In keeping with the usual practice, two Works Visits have been made during the session and on the 21st September, 40 members and friends made an inspection of the National Standards Laboratories, kindly arranged by Mr. N. A. Esserman. A further inspection was arranged for November, as many members were unable to be accommodated at the September visit. The Section held its Second Annual Social Night in June, the function being a great success.

The Papers Committee is busy planning papers and visits for next session, and full details will be announced shortly. The Twelfth Annual General Meeting of the Section was arranged for 5th October, and following the business of the meeting a Symposium of Tolerances, Finish and Fits was held, in which Messrs. Esserman, Piggot and Gladman were the contributors.

WESTERN

During the last quarter, one outstanding item was a visit to St. Anne's Board Mills at Bristol, where a limited number of members living in the locality spent a very interesting evening inspecting the plant, which produces cardboard from waste paper. A visit was also paid to Dowty Equiment Ltd. at Cheltenham in September, when some 50 members of the Section spent an enjoyable time touring the works and seeing the various items of test equipment which are required on the hydraulic systems produced by this Company.

The Section has sustained a great loss during the quarter by the death of Mr. J. T. Kenworthy, who apart from being a member of Council was also a very valued member of the Section Committee.

The Section Committee wishes the best of success to Mr. C. Newcombe, who has resigned his position as Honorary Secretary in consequence of obtaining a position near Coventry, and it is hoped that he will continue his work for the Institution in the Midland area.

WEST WALES

It is pleasing to report that unanimous agreement was reached by the Committee on the lines to be followed during the session, and the Committee has also been able to make a considerable number of contacts with the larger firms and important individuals in the district. From the

education angle, a considerable amount of support has been received from Mr. L. J. Drew, the Educational Officer for Swansea, who has been kind enough to mention the Institution of Production Engineers in the new Swansea Brochure on education. In addition, Mr. George Thompson of the Technical College, Swansea, has in many ways given his able support.

The programme for the Winter Session has been completed, and the Sub-Section looks forward to the full support of individuals and companies in the district.

WOLVERHAMPTON

The Lecture Programme for the 1948/9 Session has been completed. The first lecture on "Electronics in the Service of the Engineer," by Mr. S. H. Ghalib was a very interesting paper, and a lively discussion followed.

Since the last report Mr. E. G. Holberry, A.M.I.P.E., has been co-opted as a member of the Committee.

On 30th June a visit was arranged to Messrs. A. C. Wickman Ltd., Coventry, which proved a very instructive and interesting outing. Applications for membership continue to be satisfactory.

WOLVERHAMPTON GRADUATE

During the summer, two Section meetings, two Works Visits, three Committee meetings and two Social Sub-Committee meetings have been held. The Section meetings included a film "After the Lord Mayor's Show," and a lecture on foundry practice. Works visits were made to the Wolverhampton Die-Casting Company and the Dowty Equipment Company, Cheltenham, the latter visit being combined with a social occasion on which wives and friends were invited to take part in the Annual Coach Tour and Outing.

The Social Sub-Committee, who ably carried through the arrangements for the Annual Outing, have arranged an Easter Dance to be held on 22nd April, 1949, and a full programme of lectures and works visits has been completed, for the session.

Personal visits have been made by the Committee to over 60% of the members of the Section during the quarter.

YORKSHIRE

During the summer months, social events in the form of Golf Matches have been enjoyed by members of the Yorkshire Section. On 18th June the Annual Golf Match for "T'owd Tin Pot" was held at Otley, the winner being Mr. T. Bancroft, of Messrs. Blackburn Aircraft Co.

A very enjoyable evening was spent on 29th July when a challenge was accepted from the Leeds Association of Engineers, and a match was played at Scarcroft, which ended all square.

On Monday, 4th October, the new session started with a paper read by Dr. H. Orenstein, M.I.P.E., entitled "Production and Research Development in America."

YORKSHIRE GRADUATE

No visits or lectures have been held during the quarter due to the holiday season. A Committee Meeting was held at the Midland Hotel, Bradford on 19th July at which Mr. J. E. Hill (Chairman of Council) and Mr. W. Armstrong (Chairman of Yorkshire Section) were present. Mr. Hill and Mr. Armstrong spoke to the proposed Committee in a very straightforward manner regarding certain Section expenses which had troubled the proposed Committee members for some time. This matter was eventually settled, and Mr. Hill and Mr. Armstrong then left the meeting. The proposed Committee members agreed to serve another term of office and proceeded to deal with the Section business.

Mr. G. Coates, who has been transferred to Associate Membership, has resigned from the Committeee. His place has been taken by Mr. J. B. Clayton who has now returned to this area.

The Committee are looking forward to a successful year, as a special effort is to be made to stimulate greater interest in the meetings.

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ELECTION OF MEMBERS

MEETING OF COUNCIL, 28th OCTOBER, 1948

The following were elected to membership by Council :—

As Members :

E. G. Allsop, R. Beasley, J. W. R. Byfield, J. R. Charlton, J. Chatterton, L. H. Cheeseman, W. H. R. Dalley, P. B. Davidson, F. G. English, C. A. Gladman, K. Hayward, S. Heffernan, G. R. Hill, J. O. Knowles, G. C. J. Legg, J. W. Moffatt, P. Neil, C. L. Old, W. E. Park, R. Ratcliffe, M.B.E., R. J. Richardson, F. E. Rowland, G. Swain, R. Wood.

As Associate Members :

J. L. Ashford, H. R. Badyal, D. C. Baird, J. J. Balfour, L. R. Benton, R. A. Beran-Frisch, J. Brown, T. Brown, E. H. Burman, R. F. H. Bush, J. C. Caiger, H. W. Caldwell, J. M. Cameron, P. H. Carter, C. H. Casling, C. E. Cloudsdale, A. R. Collingridge, H. Crompton, G. Crook, B. K. Dam, A. E. E. H. Davidson, S. L. B. Farrow, R. G. Field, J. Farmery, G. A. Gardner, A. M. Garrington, J. M. George, K. L. Giare, W. H. Goodwin, J. A. Grainger, J. Gray, F. H. Groom, H. N. Hacking, R. Hacker, W. Hague, L. H. Hancock, G. C. Hepworth, A. E. Hogton, C. M. Hunter, T. W. Johnson, A. G. Jones, S. G. Jones, I. A. Jenkins, A. Johnston, A. J. Kauler, H. M. Knight, H. Littlewood, W. Lomax, F. L. Manning, W. Mearns, S. Medcraft, J. Medina, H. Moncrieff, D. R. Morley, J. L. Ness, J. G. Noble, E. A. Parry, L. M. Paynter, C. A. R. Pearce, R. H. Phillips, L. S. Pitteway, J. A. Porter, O. H. Price, W. J. Price, J. C. Pritchard, J. T. Radford, S. V. Raman, T. D. Rao, A. W. Reader, R. Reid, F. Rushton, J. Riley, E. Rodeck, J. D. Sahi, J. Schofield, F. A. Sheppard, T. G. Swain, C. Spires, J. Storrow, J. M. Taylor, C. E. Thompson, R. A. Thompson, J. J. Tobin, H. Unsworth, V. J. Vaughan, G. N. Venn, T. K. Watridge, D. J. Williams, H. Wolff, E. A. Young.

As Intermediate Associate Members :

D. H. Adams, R. J. Bailey, B. K. Banerji, R. A. Brotherton, W. Butler, F. C. Carter, W. Clark, W. G. Clements, R. Colebourne, G. W. Davies, J. B. Daws, A. Dodwell, J. W. Duffield, H. J. Eden, D. Gemmell, D. N. Ghosh, N. K. Ghosh, K. S. Gill, R. K. Grunau, H. M. Harman, F. H. S. Heidenstam, C. E. Hill, H. F. M. Hopkin, A. Holroyd, A. E. Jones, G. A. Johnson, J. Kerr, F. Knight, N. Krishnamurti, S. Layton, E. H. Mather, E. Martin, R. Mishra, M. N. Mukherjee, C. F. Neale, R. Neate, T. F. Newton, S. E. Norman, M. J. O'Hare, E. T. Pearce, C. G. Rogers, L. N. Sharma, J. J. Southwell, Y. Tandan, C. J. Thresh, A. Townsend, C. Unwin-Portsmouth, J. Waller, W. P. Ward, N. E. Webb, H. White.

As Associates :

V. J. F. Donnelly, H. L. Feibelman, K. O. Grant, D. W. Howe, W. G. A. Jenkins, W. Shaw, R. A. Straker-Nesbit, H. Wiercinski.

As Graduates :

J. P. J. Anderson, A. A. Avery, W. F. A. Ayears, P. M. Bailey, S. Baker, K. W. H. Baldock, G. A. Blackshield, R. W. H. Bennett, B. J. Bluhm, O. S. Brown, M. J. Butt, L. E. Caines, E. Chapman, F. A. Cheshire, D. C. Clark, H. S. Cox, M. Cox, J. Critchley, C. R. T. Cummings, V. F. Deeves, N. Dooley, E. D. Dunbar-Nasmith, J. R. Duncan, J. J. Farley, J. W. H.

Ferguson, J. Freel, D. V. Gallon, P. C. Grigg, P. Griggs, A. G. Gulliver, B. P. Hague, B. Hill, F. Hinchey, N. D. Hodgekiss, D. H. Horobin, F. Houghton, H. Haigh, B. Harding, N. Holmes, H. Johnson, A. G. Jones, B. A. Jones, D. E. Kent, G. H. Kent, W. E. Knott, P. S. Langton, W. J. Lampkin, P. W. Leek, V. Lee-Brown, P. H. Liardet, R. F. Loebl, A. G. Low, M. McCreedy, P. A. McElwee, V. Mitchell, C. E. H. Morriss, F. R. Mottershead, W. H. E. Parr, F. B. Pearce, J. M. Pearson, T. Roberts, J. Robinson, R. S. Russell, L. H. Sanders, K. S. Satsangi, R. T. Shackleton, B. Sharman, P. E. Simmonds, K. Shield, A. F. W. Smith, R. C. Taylor, J. R. Tomlinson, H. A. Turner, R. H. Varcoe, D. Wallace, J. H. Walmsley, L. Walmsley, N. H. Ward, N. H. Watts, J. F. Westaway, L. Wix, J. Whitehead, W. Wilkes, D. B. Williams, P. Wolkin, F. W. Woodsford.

As Students :

J. Airs, B. J. Andrews, G. R. Backer, P. Bainbridge, E. Bamford, L. J. Baxby, J. C. Beard, W. J. Bell, R. P. Bernard, M. L. G. Boughton, K. Bowden, C. D. Bowman, C. G. Bruce, F. W. Bryant, J. S. H. Budds, J. H. Burness, L. R. Carozzi, B. R. Cocks, A. J. H. Courtney, A. G. Cowe, B. W. Cox, A. Crossley, C. P. Davies, E. D. Dixon, F. J. Dobson, R. E. Driscoll, J. G. Dunbar, L. Dyer, P. M. Ferguson, J. M. Flounders, W. D. Freight, N. E. H. Gilbert, R. H. Green, H. Gibson, P. S. Gurung, G. V. C. Hamey, J. Hargreaves, J. A. Harrop, M. E. Hazlehurst, W. A. Hendrie, S. G. Hughes, W. F. Kuhn, D. Lean, K. F. Lloyd, R. Lugg, F. E. Ludwig, M. G. Mackay, F. Marvel, T. E. Matthews, J. E. Mead, A. Milburn, P. K. Mookherjee, W. Moore, D. A. Neill, P. R. Platts, D. A. H. Pennick, W. M. Pyle, P. Rapoport, K. L. Reeves, G. Robinson, B. L. C. Sayce, J. W. Sharp, E. S. Slater, K. M. Talintyre, A. N. Taylor, A. Thorley, K. E. Tragardh, W. D. Varrenti, L. F. G. Walker, J. E. Walford, K. Walmsley, R. G. Worrall.

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TRANSFERS :

From Associate Member to Member :

L. R. Beesly, R. Broadbent, F. Brown-Coombes, L. Brown, W. Cookson, P. Dunkley, I. F. E. Hollins, D. F. Horne, D. R. Kinnell, C. J. Kneller, A. H. Pearson, A. E. Riley, T. S. Shipman, J. B. Singh, C. Timms, J. Whalley.

From Intermediate Associate Member to Member :

A. V. Sadler.

From Intermediate Associate Member to Associate Member :

H. Busby, J. H. Coleman, F. Dolby, N. A. Dudley, H. Gibbon, J. F. W. Galver, W. Hewett, W. Hind, N. E. Hodge, A. T. Jordan, A. C. Keir, J. Knight, J. McCormick, A. L. Nadin, J. C. Routledge, R. V. Schulz, G. Trubshaw, L. W. Wood.

FROM GRADUATE TO ASSOCIATE MEMBER :

C. C. Beeby, A. G. Bloomer, W. Charlson, F. C. Coupe, A. Jacobs, A. Latham, V. Morley, A. Short, C. Squire, N. Sykes, E. B. Wall.

FROM GRADUATE TO INTERMEDIATE ASSOCIATE MEMBER :

A. T. Gough, F. Harling.

FROM STUDENT TO INTERMEDIATE ASSOCIATE MEMBER :

D. H. Mills.

FROM STUDENT TO GRADUATE :

G. W. Adams, W. G. Bowman, M. J. L. Butcher, I. D. Corbett, W. R. Coulton, L. Craig-Brown, D. J. I. Gray, R. E. Green, J. A. Helps, W. E. Hipkiss, K. L. Horn, B. Hollington, P. Iredale, J. Jackson, A. A. Jacobsen, H. G. Lichtenstein, D. G. McWilliams, D. Milburn, D. C. Muirhead, R. T. Mustard, G. Pateman, J. E. Pitchforth, C. G. Pfaff, J. W. Rumley, R. E. Sawyer, R. Scott, J. E. Senior, S. G. Spate, H. R. Stansfield, E. K. Stephenson, T. Tanner, G. C. Wadsworth, J. Wardle, C. O. Webb, D. A. L. West, G. R. Willcocks, J. T. Wilson.

REPORT OF ANNUAL GENERAL MEETING

THURSDAY, 28th OCTOBER, 1948.

The 27th Annual General Meeting of the Institution was held on Thursday, 28th October, 1948, at 4 p.m., at the Institution's Headquarters, 36, Portman Square, London, W.1. Mr. J. E. Hill, Chairman of the Council, was in the Chair.

The CHAIRMAN said that there would be no Presidential Address, as that had been delivered by Dr. Schofield at the First National Convention of the Institution at Bournemouth. Dr. Schofield was unable to be present at the Annual Meeting as he was on his way back from the United States of America.

Notice convening Meeting

The DIRECTOR AND GENERAL SECRETARY (Major C. B. Thorne, M.C.) read the Notice convening the Meeting.

Minutes

The Minutes of the previous Annual General Meeting, which had been circulated, were taken as read and were confirmed and signed.

Report on Election of Members of Council

The DIRECTOR AND GENERAL SECRETARY read a list of the Officers and Members of Council for 1948/49, as at the 1st July, 1948, and of the Officers and Members of the Australian and South African Sub-Councils.

Annual Report of the Council

The CHAIRMAN read the Annual Report of the Council for 1947/48 as follows, and proposed its adoption:

"Your Council has pleasure in presenting the following report for the year 1947/48. The Institution has made considerable progress during the past twelve months, both in the growth of its membership and in the widening of its activities. It has co-operated on several occasions with Government Departments, and is playing an ever increasing part in the improvement of Productivity throughout the country.

INSTITUTION ACTIVITIES

(*a*) MIDLAND ADVISORY COUNCIL ON INDUSTRIAL PRODUCTIVITY.

During the early part of 1948, the Institution was invited by the University of Birmingham to co-operate in the formation of a Midland Advisory Council on Industrial Productivity. A strong delegation headed by the President, Dr. H. Schofield, C.B.E.,

M.I.P.E., and the Rt. Hon. Lord Sempill, A.F.C., Hon.M.I.P.E., and including the Director and General Secretary, attended the inaugural conference of the Midland Advisory Council at the Birmingham University on 28th May. At this Conference an executive Committee was elected under the Chairmanship of Mr. J. J. Gracie, M.I.P.E., and included Sir Arthur Smout and Professor T. U. Matthew, both members of this Institution. The Midland Advisory Council is now forming a number of Panel Teams to investigate the various industrial problems in the Midland area, and the Institution has been invited to nominate two representatives on the Panel to be formed on Iron Foundries. The Institution's representatives will be Mr. J. W. Berry, M.I.P.E. of the National Foundry College, and Mr. R. C. Fenton, M.I.P.E.

(*b*) Co-operation with the British Institute of Management

Among the members of the newly constituted Council of the British Institute of Management, are the following members of the I.P.E. :—

Lt.-Col. L. Urwick, O.B.E., M.C., Vice-Chairman of the Council; Sir Norman Kipping, Sir Charles Bartlett, Mr. Mark H. Taylor and Mr. T. G. Rose.

The Institution is also co-operating with the B.I.M. through its representative, Mr. B. H. Dyson, M.I.P.E., who is serving on the Overseas Relations Co-ordinating Committee.

(*c*) Statistical Quality Control

The Minister of Supply, then the Rt. Hon. John Wilmot, invited the Institution, through its President, Mr. Norman Rowbotham, C.B.E., to consider the inclusion of Statistical Quality Control in the syllabus of professional examinations held under its auspices. The matter was at once referred to the Institution's Education Committee, who decided to include this subject forthwith in the Graduateship Examination, and to give serious consideration to its inclusion in the Associate Membership Examination. In addition, it was felt that this branch of Production Engineering technique was of such importance that all local branches were asked to include a discussion on the subject in their Section Programmes. As a result of these discussions, a full report was drawn up and collated for presentation to H.M. Government in April 1948. The Institution considered that the subject had great possibilities in its application to a wide field of management, in view of the ever increasing need for analysis of management statistics. An application of the method of Control Charts might lead to increased managerial efficiency. The Institution further took the view that the technique had not always justified its introduction in the past, but was nevertheless,

capable of a great contribution to efficiency and productivity when applied to problems whose characteristics justified this method of treatment.

FIRST NATIONAL CONVENTION

In July 1947, Council decided to put in hand the preparations for a First National Convention to be held at Bournemouth in September 1948. This decision was taken in view of the pre-eminent position of the engineering industry in the economic affairs of Great Britain, together with the urgent need for improving the quality of British products, increasing the rate of their production, and lowering costs. The Institution was very fortunate in securing the acceptance of the three outstanding personalities who agreed to speak at the Convention: General Sir Bernard Paget, G.C.B., D.S.O., M.C., addressed the delegates on the important subject of "Leadership," Mr. E. W. Hancock, M.B.E., M.I.P.E., undertook the difficult task of presenting "Britain's Industrial Problems" and Lt.-Gen. Sir Ronald Weeks, K.C.B., C.B.E., D.S.O., M.C., T.D., concluded the major addresses by outlining "Britain's Industrial Future." As such subjects are uppermost in the minds of all who are responsible for the direction of Britain's production in this stage of her history, all members should be proud of the fact that this organisation was able to create an opportunity for the discussion of these major issues, by such highly qualified individuals.

Appointment of Education Officer

During the year 1948, the Institution made what may well prove to have been one of the most important decisions in its history, namely the appointment of a full time Education Officer. On taking up his appointment, Mr. T. B. Worth was given amongst other duties the following major tasks to perform :—

(i) To establish liaison with Government Departments, local authorities, educational institutions, professional bodies and industry, in order to assess facilities and future needs in the field of technical education.

(ii) To assist the Education Committee in the formulation of the Institution's policy in technical education in the light of information obtained.

(iii) To submit proposals to the Director and General Secretary designed to implement this policy, and to put such proposals into effect, and

(iv) To maintain close contact with all local Sections, and to assist and advise Section Committees in all educational matters.

By the appointment of an Education Officer as dynamic and highly qualified as Mr. Worth, the Institution aims not only at

assisting industries to appreciate the importance of the Production Engineer, but to tender the best possible advice and help derived from frequent contact with the problems confronting production executives, to those educational organisations responsible for the training of Production Engineers.

Associate Membership Examination

Recommendations of the Education and Membership Committees for an Associate Membership Examination were placed before Council at a meeting held in Birmingham on 15th July, 1948. Council approved the recommendations of the Committee, which will take effect from the 1st September, 1950.

The examination is divided into three parts, Part I and II qualifying for Graduateship only. The Ministry of Education has been fully kept informed of the developments in the preparation of the new examination scheme, and the reactions of the Ministry and Technical Colleges have up to the present time been most favourable.

In the development of this new examination structure, full regard has been paid to the existing Higher National Certificate courses in Production Engineering and also to the recommendations of the Urwick Report in Management Training. It is considered that the close relationship of the Institution's new examination requirements with the recent developments in the provision of courses in Technical Colleges, will not only safeguard the status of the membership of the Institution, but should also increase the provision of facilities that will enable and encourage good men to seek admission to the Institution.

NATIONAL PRODUCTIVITY

At a reception held in London on 6th February, 1948, which was attended by the Lord President of the Council, the Rt. Hon. Herbert Morrison, the Institution was able to make public a number of achievements in the field of productivity, for which individual members of the Institution have been directly responsible.

The publication of these outstanding achievements in the national and technical press did much to make known the part that members of this Institution are playing in the steady improvement of the industrial life of the nation.

RESEARCH

In view of the fact that the Institution's Research Department at Loughborough has now been formed into a national organisation, the Production Engineering Research Association of Great Britain, Council feel that the Institution's Research Committee should undertake some research work of a broader nature, including among other things, " Operational Research," with a particular reference

to mechanical handling with a view to improving rates of production. The Institution has therefore re-constituted its Research Committee, and broadened its terms of reference. Like all other Committees, it will include the President and the Chairman of Council as *ex officio* members, and will be guided by the Vice-Chairman of Council, Mr. W. C. Puckey, its newly elected Chairman.

INSTITUTION'S HEAD OFFICE

The Institution's Head Office is now re-established at 36, Portman Square. In rebuilding these premises, the original Georgian character of the building has been retained, but the opportunity was taken at the same time to adopt modern colour schemes and introduce modern office equipment. In consequence, the Institution now has a first class headquarters, of which every member should be justly proud.

SECTION ACTIVITIES.

(*a*) WOLVERHAMPTON SECTION P.M.H. CONFERENCE—22ND MAY, 1948

A successful Conference on " Production Per Man-Hour " was organised by the Wolverhampton Section under the Chairmanship of Mr. A. J. Aiers, President of the Section. The Conference was opened in the Wolverhampton and Staffordshire Technical College by the Mayor, Alderman H. E. Lane, J.P.

Addresses on this important subject were given by Major J. Freeman, M.P., Joint Parliamentary Secretary of the Ministry of Supply ; Monsieur Robert Caussin, Adminstrateur-Directeur of the Belgium National Committee for Scientific Organisation ; Miss A. G. Shaw, M.A., M.I.P.E., President of the Motion Study Society of Great Britain ; the Rt. Hon. Lord Sempill, A.F.C., Hon.M.I.P.E., F.R.Ae.S..; Mr. James Y. Scott, Member of the American Society of Tool Engineers ; Mr. B. H. Dyson, M.I.P.E., F.I.I.A. ; Professor T. U. Matthew, M.I.P.E., and Mr. Norman Rowbotham, C.B.E., M.I.P.E.

The addresses at the meeting were of a very high order, and it is hoped that many more Sections will follow the example of Wolverhampton in organising functions of this nature, the value of which cannot be over-emphasised.

(*b*) JOINT CONFERENCE AT LUTON—30TH APRIL—1ST MAY, 1948

A Conference to promote interest in and foster ideas on industrial problems was organised jointly by the Luton Section of the Institution and four other professional bodies, under the title " Whither Management? " The guest speakers at this very successful Conference included Sir Frederick Mander, M.A., M.Sc., Sir Charles Renold, Sir Charles Bartlett, Mr. J. B. Sutherland, Commander Kent, R.N., Lord Forester, Mr. G. Chelioti and Mr. R. K. Fleming.

(*c*) SECTION HONORARY SECRETARIES' CONFERENCE

A Conference of Section Honorary Secretaries of the Institution was held at Birmingham on 26th May, 1948, and the attendance numbered 20. It has been found that the administration of the Institution can be greatly improved by the discussion at these Conferences.

(*d*) FORMATION OF NEW SECTIONS

Liverpool Section.

Full Section Status was granted to Liverpool in January 1948. In view of the fact that this Sub-Section was inaugurated as recently as September 1947, the members are to be congratulated in achieving Section Status in so short a time.

West Wales Sub-Section.

The formation by the South Wales and Monmouthshire Section of a West Wales Sub-Section, with Swansea as its centre, has been formally approved by Council, and its first meeting was held on 11th March, 1948.

Reading Sub-Section.

It is hoped to announce shortly the establishment of a Sub-Section of the London Section with its centre at Reading.

(*e*) WORK OF SECTIONS ABROAD

(i) *Australia.*

The President would like to place on record the Institution's appreciation of the progressive and businesslike manner in which the Australian Sub-Council conducts the Institution's affairs in the Commonwealth. It would be hard to find a better example of collaboration, and in view of the vital part which is played by the Australian Sections in the affairs of the Institution generally, the President would like to convey a personal tribute to the President, Chairman and members of the Australian Sub-Council for their splendid work during the last few years. Their active, loyal and progressive co-operation in furthering the Institution's interests in Australia has been of the greatest value.

(ii) *India.*

Despite the recent difficult local conditions, the Calcutta Section is holding regular meetings. Considerable progress has been made and with the steady growth in membership this Section hopes to increase its activities even more in the coming year.

There is a considerable demand for a local Section of the Institution in Bombay, and it is hoped that it may be possible to form a Section there in the very near future.

(iii) *South Africa.*

Institution activities in South Africa are progressing favourably.

INSTITUTION AWARDS

(*a*) LORD AUSTIN PRIZE

This prize was awarded in 1947 to the Honorary Secretary of the Derby Section, Mr. A. Short, Grad.I.P.E. (now transferred to Associate Membership) for his paper on "The Comparative Usefulness and Economics of the Die Casting Process."

(*b*) INSTITUTION MEDALS

The Medals for the best papers read to the Institution during 1947/48 have been awarded as follows :—

For the Best Paper by a Member : Mr. W. H. Tait, M.M., F.I.M., M.I.Mech.E. (Metallurgical and Engineering Consultant) for his paper on "Plain Sleeve Bearings, Materials and Design," presented to the London Section of the Institution on 24th October, 1946.

For the Best Paper by a Non-Member : Mr. R. E. Wilson, M.I.A.E. (Managing Director, Fescol Ltd., London) for his paper on "The Relative Merits of Electrodeposited Nickel and Chromium," presented to the Yorkshire Section of the Institution, on April 7th, 1947. Mr. Wilson has since joined the Institution.

The Medals were presented at a meeting of the London Section of the Institution on 8th April, 1948. A number of prominent members of the Institution attended this function.

GRADUATESHIP EXAMINATION 1948

Of the 119 candidates who sat for the Graduateship Examination this year, 93 passed and 17 failed. Nine candidates were referred in one subject. These figures are encouraging and compare very favourably with the figures for last year, when out of 86 candidates 68 passed and 18 failed.

STANDARDS

The Standards Committee is actively continuing its work, and during the past year it has been instrumental in selecting and appointing many members of the Institution to serve on B.S.I. Technical Committees. Draft Specifications have been circulated to Committee Members and selected panels of members, and many useful comments and suggestions have been forwarded to the British Standards Institution. A questionnaire on Interference Fits, drawn up by members of the Committee, has recently been circulated to all Sections, and it is hoped to obtain by this means some valuable data for the assistance of the B.S.I. Committee on Limits and Fits, in connection with the revision of B.S. 164.

Several suggestions for standardisation from members of the Institution have been examined by the Standards Committee and forwarded to B.S.I. In several instances these applications have

resulted in the formation of B.S.I. Sub-Committees for the specific purpose of considering the suggestions, with a view to issuing British Standards.

MEMBERSHIP STATISTICS

There has been a net increase of 618 members during the year. The total number of members at 30th June, 1948, was 7,287, made up as follows :—

Honorary Members	6
Members	1,226
Associate Members	2,348
Int. Associate Members ...	1,364
Associates	148
Graduates	1,170
Students	815
Affiliated Firms	210
TOTAL ...	7,287

INSTITUTION JOURNAL

In response to a suggestion by Council, a series of biographies of prominent members of the Institution, under the title " Institution Personalities," is being published in the Journal. An attempt is also being made to re-establish the Abstracts service for members. An appeal for volunteers from amongst members to act as honorary external correspondents in this connection has now been published in the Journal.

Excellent relations have been maintained with the Technical Press, who are always ready to co-operate and assist in connection with the publication of papers.

FINANCE

Members of the Institution will have noticed from the Annual Accounts published in the October issue of the Journal that this year there is an excess of expenditure over income of £1,330. Despite the fact that the cost of living has risen considerably during the last nine years, the rates of subscription for membership of the Institution have not been proportionately increased to meet the changing economy. The Institution has increased its membership from approximately 2,000 in 1939 to 7,287 at 30th June, 1948, but of the total membership a heavy proportion is included in the junior grades, for whom the cost of service is no less than that for the senior membership. For this reason, the current income is not meeting the rate of current expenditure. As members will have appreciated from the foregoing paragraphs of this Report, the Institution has now reached a most important stage of its history and growth, and must now face a situation which demands still further progress if it is to become a vital factor in the economic affairs of the nation.

The prime reason for the present deficit is therefore that our income derived from membership subscriptions is inadequate to cope with the growth of the Institution. The greatly increased cost of the Journal due to the increased membership must also be taken into account, together with the increased expenditure on postage and stationery.

Careful investigations have been made by the Finance Committee into the possibility of exercising economy but they are of the opinion that the whole organisation is being run as efficiently and as economically as possible. Therefore, the only alternative is to consider a rise in the rates of subscription, in order that our economy may be placed on a sounder basis in future. These matters are receiving careful consideration at the present time, and a detailed statement will be made early in the present financial year.

HONOURS

The Institution has pleasure in recording that the award of O.B.E. was conferred by H. M. The King on Mr. S. W. D. Lockwood, A.M.I.P.E.

OBITUARY

Mr. H. A. Hartley, M.I.P.E.

The Institution has suffered a grievous blow this year in the death of Mr. H. A. Hartley, Vice-President of the Institution, Past Chairman of Council and Past President of the Eastern Counties Section. Mr. Hartley was elected the first Chairman of the Standards Committee on its formation in 1934, and represented the Institution on the B.S.I. Mechanical Industries Committee until 1947. In recognition of his outstanding services to the Institution, Mr. Hartley was elected an Honorary Member in April 1948. He combined a public-spirited and unselfish nature with outstanding administrative gifts, and his example will be an inspiration to his fellow members. An appreciation has appeared in the August 1948 issue of the Journal.

Mr. J. G. Young, M.I.P.E.

The death of Mr. J. G. Young, a Founder Member of the Institution and past Chairman of Council, is also recorded with deep regret. During the course of his long association with the Institution, he served on the Membership, Standards and Finance and General Purposes Committees, and the preliminary negotiations for the formation of the South African Sub-Council were made possible by his personal visit to South Africa. He took the keenest interest in all the activities of the Institution, and will be greatly missed, particularly by the Cornish Section.

Mr. R. H. Youngash, M.I.P.E.

The Institution has also suffered a grave loss in the death of

Mr. R. H. Youngash, another Founder Member who gave untiring service on the Membership and Education Committees for many years. He also served on the Council of the Institution, and will be sadly missed by his many friends.

MR. M. EADY, M.I.P.E.

The sudden death of Mr. Marshall Eady, President of the Australian Sub-Council and President of the Melbourne Section, was a heavy blow to the Institution in Australia.

Mr. Eady had played a prominent part in the development of the Institution's activities in that country.

MR. J. T. KENWORTHY, M.I.P.E.

Since the end of the financial year, the death of Mr. J. T. Kenworthy has also to be recorded with regret. He will be long remembered for his devoted work on Council and on the Education and Membership Committees, and for the courage and enthusiasm with which he continued to take part in the Institution's activities despite increasing ill-health. A biographical note has appeared in the April 1948 issue of the Journal.

The deaths of the following members are also announced with great regret :—

Mr. F. R. Barratt, M.I.P.E. (South Africa).
Mr. W. E. Butler, A.M.I.P.E.
Mr. W. R. Champion, A.M.I.P.E.
Mr. T. W. R. B. Colley, A.M.I.P.E.
Mr. E. R. Dare, Int.A.M.I.P.E.
Mr. M. D. Denley, Stud.I.P.E.
Mr. G. W. Dixon, M.I.P.E.
Mr. C. Edwards, Int.A.M.I.P.E.
Mr. H. Flatman, A.I.P.E.
Mr. J. F. Fraser, Int.A.M.I.P.E.
Mr. T. H. Galbraith, M.I.P.E.
Mr. E. W. L. Gardner, M.I.P.E.
Mr. V. Gartside, M.B.E., M.I.P.E.
Mr. S. Geddes, M.I.P.E.
Mr. C. Grew, M.I.P.E.
Mr. W. Hall, M.I.P.E.
Mr. A. J. Hitch, A.M.I.P.E.
Mr. W. Holt, A.M.I.P.E.
Mr. J. Leishman, M.I.P.E.
Mr. D. S. Loudon, A.M.I.Mech.E., A.M.I.A.E., M.I.P.E.
Mr. J. C. Oliver, M.I.P.E. (Melbourne)
Mr. E. J. Piggott, M.I.P.E.
Mr. A. J. Price, Int.A.M.I.P.E.
Mr. F. A. Pucknell, M.I.P.E.
Mr. J. Rankin, M.I.P.E.

Mr. J. Rhodes, A.M.I.P.E.
Mr. E. O. Schreiber, M.I.P.E.
Mr. I. S. Sinclair, M.I.P.E.
Mr. W. J. Stockley, A.M.I.P.E.
Mr. A. B. Townsend, M.I.P.E.
Mr. J. Vairy, Grad.I.P.E."

Commenting on the paragraph dealing with the Institution's Head Office, the CHAIRMAN expressed his personal agreement with the statement that the Institution had now a first-class headquarters, of which every member could be proud. He hoped that those attending the Annual General Meeting would take the opportunity of inspecting it, including the rooms upstairs; he thought they would be impressed, as he himself had been.

Mr. T. Fraser seconded the motion for the adoption of the Report, which was carried.

Accounts

The CHAIRMAN then presented the Statement of Income and Expenditure, Balance Sheet, and Auditor's Report, of which copies had been distributed, and invited comments.

The Accounts were adopted on the motion of Mr. H. J. Swift, seconded by Mr. T. Fraser.

Election of Auditors

On the motion of Mr. G. H. Hales, seconded by Mr. H. Nutt, Messrs. Gibson, Appleby & Co., Chartered Accountants, were re-elected Auditors to the Institution for the year 1948/49.

Election of Solicitors

On the motion of Mr. H. J. Swift, seconded by Mr. J. D. Scaife, Messrs. Syrett & Sons, of Lincolns Inn, were re-elected Solicitors to the Institution for the year 1948/49.

Votes of Thanks

Mr. W. C. Puckey (Vice-Chairman of Council) proposed a vote of thanks to Mr. Norman Rowbotham, C.B.E., for acting as President for the previous year, and to Dr. H. Schofield, C.B.E., for his Chairmanship of the Council in the same year.

Mr. E. P. Edwards seconded the motion, which was carried.

The CHAIRMAN said it was his privilege to move a vote of thanks to the Section Honorary Secretaries, who worked very hard for the Institution, and to whom its best thanks were due, and also to the Director and General Secretary and his staff for the excellent and

very hard work that they had done during the past session, especially in connection with the National Convention and many meetings which had taken place in the provinces.

The vote of thanks was carried with acclamation.

The DIRECTOR AND GENERAL SECRETARY, responding on behalf of himself and the staff, said it was a great pleasure to serve such an enthusiastic Institution, and the staff felt that they were a part of it.

A vote of thanks to the Chairman was proposed by Mr. H. J. Swift, seconded by Mr. T. Fraser and carried with acclamation.

The Annual General Meeting then terminated.

THE CALCULATION OF DRAWING STRAINS IN CIRCULAR SHELLS

by KENNETH L. JACKSON,*
M.Sc.(Eng.), A.M.I.Mech.E., Grad.I.P.E., Mem.A.S.M.E.

The design of press tools has, in the past, been very much a " hit and miss " business, and it seems that present researches into the nature of drawing should yield very valuable information for the practical engineer. In the case of circular blank computations, the normal procedure is to assume constancy of plate thickness during drawing, so that the area of the finished shell may be equated to that of the undrawn blank, and hence the blank diameter obtained. However, it is well known that the plate thickness is not constant during drawing, and the radial strains incurred are of a complicated character. This paper is an attempt to show how these plastic strains may be evaluated under the conditions of certain assumptions, and to analyse the mechanics of drawing.

The photo-grid technique[1] was employed for the purposes of examining the distribution of radial strains (*i.e.*, down the walls of the drawn circular shells), the final dimensions of the grids being measured under the microscope and the strains calculated therefrom. The grid spacings were 1 mm. initially. Measurements of radial, hoop and thickening strains (the latter being measured directly by means of a micrometer fitted with conical ended spindle and anvil) were taken and graphs were drawn up to illustrate the nature of the strain distributions in the case of 0·010″ Ebbw Vale tinplate with C16 tin coating. Lubrication consisted of the application of paraffin-wax to the undrawn blanks. The speed of the mechanical crank press used was 140 cycles per minute. The application of the pressure between the pressure faces of the dies was by means of the usual rubber buffer, and the initial buffer pressure (*i.e.*, at commencement of draw) was adjusted in each case to prevent the formation of wrinkles—the amount of the pressure depending of course on the radius of the blank. All shells drawn had a small corner radius between the wall and base, of not more than 0·04″.

THE MECHANICS OF DRAWING

Professor H. W. Swift discussed the process of drawing[2] and presented the problem in this way. Each element of metal in the partly drawn stage is subject to a radial stress ($\widehat{rr}$), a hoop stress ($\widehat{\theta\theta}$) and a thickness stress ($\widehat{zz}$). As a first approximation, however, the $\widehat{zz}$ may be

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neglected in comparison with the $\widehat{rr}$ and $\widehat{\theta\theta}$. Corresponding to these stresses, there are incremental changes of strains (plastic) which may be denoted as δE_r, δE_θ and δE_z for the radial, hoop and thickness directions, the δE_z not being zero even though the $\widehat{zz}$ is assumed zero.

If it is assumed that the criterion[3] of plastic flow is $\widehat{rr} - \widehat{\theta\theta} = f_0$ where f_0 is the flow stress, the values of $\widehat{rr}$ and $\widehat{\theta\theta}$, may be calculated (see the Appendix). At any stage of the draw, the $\widehat{rr}$ at the edge of the blank will be zero so that the maximum $\widehat{\theta\theta}$ will obtain, this being $-f_0$. At the minimum radius (*i.e.*, shell radius R_1—see figure I) the $\widehat{rr}$ will be at its maximum value and the $\widehat{\theta\theta}$ at its minimum value. Since the radial tension due to $\widehat{rr}$ is the main factor as regards rupture of the shell, it is obvious that the point most likely to cause rupture is at the radium R_1. Further, since the value of $\widehat{rr} = f_0 \log_e \left(\frac{a}{R}\right)$ where a is the blank radius during drawing, the maximum value of $\log_e \left(\frac{a}{R}\right)$ will be when a is a maximum, *i.e.*, at the initial stages of drawing. Hence if the shell is to rupture at all, it will be at the commencement of drawing.

The hoop strain is the cause of the tendency to wrinkle and also the tendency to produce thickening strains, so that one would expect the maximum thickening strain to occur at the edge of the blank, a fact which is borne out by experience. The thicker the blank is initially, the less chance there is of puckering without the application of an external pressure across the thickness direction, and one could describe this phenomenon as being due to the increased second moment of area of section, rather like the manner in which a strut is increased in rigidity by increasing the section inertia.

Regarding the thickening strains, during drawing the plate thickness between R_1 and a is approximately constant, but is actually greater than the initial thickness. This thickening occurs all the time during the drawing (see Figure 2), and is accompanied by radial stretches and hoop compressions.

IRONING

Assuming that the clearance between the form block and female die is more than maximum thickness which the walls acquire after drawing, an element which is situated at the brink of the die radius is forced round this radius and into the vertical wall. During this process it is reduced somewhat in thickness and increased in length (corresponding to a radial strain) by virtue of the friction forces at the contact surfaces and the bending and unbending forces which occur. The normal meaning

of " ironing " is the reduction of thickness of an element due to being squeezed or pulled through between two faces which are at a smaller distance apart than the initial thickness of the element. In the present problem we see that there is a constraint on one side of the element only, so that I propose to call this " semi-constrained-ironing". The extra strain in the radial direction due to this semi-constrained-ironing amounts to something of the order of 10 per cent. in these particular tests, and the experimental evidence tends to show that it is approximately a constant amount for a given material and thickness. Hence an experimental constant must be determined in order to establish the total radial strains incurred in the " drawing " process, the word " drawing " here implying the composite action of pure drawing-in and the semi-constrained-ironing.

EXPERIMENTAL RESULTS

The set of curves for radial strain distribution (ϵr) plotted against original blank radius are seen in Figure 3, these being the results for a shell of radius 33·1 mm. The tendency for the curves to drop at the extreme top of the blank is probably due to the fact that the composite action of drawing-in and semi-contsrained-ironing is replaced by merely drawing-in at the end of the operation. This occurs because the blank tip is released from the pressure faces whilst passing over the die radius. In order to compare the theoretical drawing strains with the actual, it was necessary to dissociate the semi-constrained-ironing strains from the composite strains as given in the curves for Figure 3. These ironing strains were obtained by testing ordinary strips of plate which were " drawn " in a rectangular die on the long ledge, so as to obtain the ironing affect without the drawing effect. The average ironing strains were plotted, as shown in figure 4 and also the average composite radial strains calculated from the set of curves in Figure 3 were plotted along the same base for comparison. The dotted curve of average drawing strains is the theoretical one as given by the analysis in the Appendix. By subtracting the ironing strain ordinates from the composite strain ordinates, the resultant curve must represent the actual pure drawing-in strains, which as is seen does compare reasonably with the theoretical values. Whatever differences which occur are due to the mathematical approximations made, the basic assumptions regarding the nature of plastic flow, and the " mechanical " approximations assumed for the purposes of simplicity. Nevertheless, the experimental results are encouraging.

Finally, the curves in Figure 5 illustrate the two principal strains E_r and E_z in general cases, and it is interesting to note the manner in which the thickening strains behave. The initial negative

thickening strain is not given by the theory (in the particular cases considered), which yields the solution of an increasing thickening strain right from the commencement of draw, and therefore always positive. However, the semi-constrained-ironing effect is the cause of the extra thinning throughout the operation, and the algebraic sum of the two produces the curves which appear in Figure 5.

In conclusion, it may be pointed out that the assumption of constant thickness after drawing for the purposes of blank calculations is only true when the areas of the thickening strain curve above and below the abscissa cancel out, *i.e.*, when the mean thickening strain is zero. In fact when the blank radius is more than 1·35 times the shell radius, this assumption is not true, there being an excess of positive area, which means that the average thickening strain is some positive amount, and under these circumstances, the average radial strain will be that as given by the theoretical curve plus the average ironing strain on the strips as determined by experiment. This is about 10 per cent. in the case of the 0·010 tinplate used in these tests.

APPENDIX

For simplicity of analysis, the maximum shear stress theory of elastic failure may be used as the criterion of plastic flow, namely, $\widehat{rr} - \widehat{\theta\theta} = f_0$ (f_0 being the flow stress). By experimental evidence the following theories are put forward, namely: (1) constancy of volume, and (2) the ratio of the difference between the principal stresses and the principal strains is constant. Mathematically, these are expressed in the following way:—

$$\delta E_r + \delta E_\theta + \delta E_z = O \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\frac{\widehat{rr} - \widehat{\theta\theta}}{\delta E_r - \delta E_\theta} = \frac{\widehat{\theta\theta} - \widehat{zz}}{\delta E_\theta - \delta E_z} = \frac{\widehat{rr} - \widehat{zz}}{\delta E_r - \delta E_z} \quad . \quad . \quad . \quad . \quad (2)$$

In this particular problem, since $\widehat{zz} = O$, equation (2) is written:

$$\frac{\widehat{rr} - \widehat{\theta\theta}}{\delta E_r - \delta E_\theta} = \frac{\widehat{\theta\theta}}{\delta E_\theta - \delta E_z} = \frac{\widehat{rr}}{\delta E_r - \delta E_z} \quad . \quad . \quad . \quad . \quad (3)$$

On the appropriate substitutions for f_0 and δE_z in equation (3), the first two terms yield:—

$$\frac{\delta E_r}{\delta E_\theta} = \frac{2f_0 + \widehat{\theta\theta}}{\widehat{\theta\theta} - f_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and the first and third terms yield:—

$$\frac{\delta E_r}{\delta E_\theta} = \frac{f_0 + \widehat{rr}}{\widehat{rr} - 2f_0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Considering now the equilibrium of the element shown in Figure

6 (assuming that there is no relative change in thickness of this element and that dynamic forces are negligible), by resolving radially the following equation is obtained:—

$$\widehat{rr}R\delta\theta - \left[\widehat{rr}R\delta\theta + \frac{\partial}{\partial R}(\widehat{rr}R\,\delta\theta)\,\delta R\right] + \left[2\widehat{\theta\theta}\delta R + \frac{\partial}{\partial\theta}(\widehat{\theta\theta}\delta R)\,\delta\theta\right] sin\left(\frac{\delta\theta}{2}\right) = O$$

Which reduces to :— $\dfrac{\partial(\widehat{rr}R)}{\partial R} - \widehat{\theta\theta} = O$

i.e., $$R\frac{\partial\widehat{rr}}{\partial R} = \widehat{\theta\theta} - \widehat{rr} \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The evaluation of the radial stress must depend upon the criterion $\widehat{rr} - \widehat{\theta\theta} = f_0$, hence

$$-R\frac{\partial\widehat{rr}}{\partial R} = f_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Integrating, $\widehat{rr} = -f_0 \log_e R + C$

For boundary conditions, when $R = a$ (at any stage of draw) $\widehat{rr} = O$, so that $C = f_0 \log_e a$

$$\therefore\ \widehat{rr} = f_0 \log_e \left(\frac{a}{R}\right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

Also $\widehat{\theta\theta} = \widehat{rr} - f_0 = f_0 \left[\log_e \left(\frac{a}{R}\right) - 1\right] \quad . \quad . \quad . \quad (9)$

Substituting the values of $\widehat{rr}$ and $\widehat{\theta\theta}$ in either equations (4) or (5) we obtain the result :—

$$\frac{\delta E_r}{\delta E_\theta} = \frac{\log_e \left(\frac{a}{R}\right) + 1}{\log_e \left(\frac{a}{R}\right) - 2} \quad . \quad . \quad . \quad . \quad . \quad (10)$$

Further, since $\delta E_r + \delta E_\theta + \delta E_z = O$, then $\dfrac{\delta E_z}{\delta E_\theta} + 1 = -\dfrac{\delta E_z}{E\delta_\theta}$

Hence $$\frac{\delta E_z}{\delta E_\theta} = \frac{1 - \log_e \left(\frac{a}{R}\right)}{\log_e \left(\frac{a}{R}\right) - 2} \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Again referring to Figure 6, the value of δE_θ may be obtained from geometric considerations:—

$$\delta E_\theta = \frac{2\pi\,(R + \delta R) - 2\pi R}{2\pi R} = \frac{\delta R}{R} \quad . \quad . \quad . \quad . \quad (12)$$

Substituting in equations (10) and (11) and reducing:—

$$\therefore \delta E_r = \frac{\delta R}{R}\left\{1 + \frac{3}{\log_e\left(\frac{a}{R}\right) - 2}\right\} \quad . \quad . \quad . \quad (13)$$

$$\text{and } \delta E_z = -\frac{\delta R}{R}\left\{2 + \frac{3}{\log_e\left(\frac{a}{R}\right) - 2}\right\} \quad . \quad . \quad . \quad (14)$$

The mathematical difficulty from the point of view of solving these two integrals is that a is a variable, being a function of R, and in order to attempt a solution, an approximation may be made. In Figure VI the element at R' is distant K from the blank radius. During drawing this element corresponds to R, such that $(a - R) = (R_B - R') = K$ neglecting the mean strain of the length K in comparison with the total radial strain in the element, in moving to R_1. Hence if K is considered constant, the integrals may be solved approximately, and equations (13) and (14) may now be written:—

$$\delta E_r = \frac{\delta R}{R}\left\{1 + \frac{3}{\log_e\left(1 + \frac{K}{R}\right) - 2}\right\} \quad . \quad . \quad . \quad (15)$$

$$\delta E_z = \frac{-\delta R}{R}\left\{2 + \frac{3}{\log_e\left(1 + \frac{K}{R}\right) - 2}\right\} \quad . \quad . \quad . \quad (16)$$

Since $\log_e\left(1 + \frac{K}{R}\right) = \frac{K}{R} - \frac{1}{2}\left(\frac{K}{R}\right)^2 + \text{- - - -}$ we may take as many terms as are required, according to the accuracy desired. Although K is not necessarily small, it is obvious that the larger K becomes, the smaller are the strains incurred, because the corresponding R is tending to R_1. It was found that by taking only the first terms of the expansion, the result gave an error of not more than 4 per cent. at the worst position and an average error of about 2 per cent. over the range (in the case of $R_B = 1{\cdot}6\ R_1$), as compared with the strain distribution as given by graphical integration of the equations. On substituting $\frac{K}{R}$ for $\log_e\left(1 + \frac{K}{R}\right)$ in equation (15):—

$$\therefore \int_0^{E_r} dE_r = \int_R^{R_1} \frac{dR}{R} + \int_R^{R_1} \frac{3dR}{K - 2R} \quad . \quad . \quad . \quad . \quad (17)$$

$$\text{Integrating, } E_r = \log_e\left\{\left(\frac{R_1}{R}\right)\left[\frac{2R - K}{2R_1 - K}\right]^{\frac{3}{2}}\right\} \quad . \quad . \quad (18)$$

The value of E_r is a logarithmic strain, and since it is more convenient to put it into the form of an " engineering strain " or percentage strain,

$$E_r^{(\%)} = 100\left\{\left(\frac{R_1}{R}\right)\left[\frac{2R - K}{2R_1 - K}\right]^{\frac{3}{2}} - 1\right\} \quad . \quad . \quad (19)$$

Similarly, we obtain a result for the thickening strain:—

$$E_z^{(\%)} = 100\left\{\left(\frac{R}{R_1}\right)^2\left[\frac{2R_1 - K}{2R - K}\right]^{\frac{3}{2}} - 1\right\} \quad . \quad . \quad (20)$$

Also, from equation (12) the hoop strain becomes, on integrating,

$$E_\theta^{(\%)} = 100\left(\frac{R_1}{R} - 1\right), \text{ (which is negative)} \quad . \quad . \quad (21)$$

The distributions of the above three strains are shown in Figure 2(b) in the case of $R_B = 1{\cdot}6\,R_1$. Generally, if $R_B = nR_1$, where n is some constant (which in practice is not usually more than 1·6–1·8 for a single stage draw), then the maximum strains are found to, on substituting $K = O$ in equations (19), (20) and (21):—

$$\left.\begin{aligned} E_r^{(\%)}\,(\text{max.}) &= (\sqrt{n} - 1)100 \\ E_z^{(\%)}\,(\text{max.}) &= (\sqrt{n} - 1)100 \\ E_\theta^{(\%)}\,(\text{max.}) &= \left(\frac{1}{n} - 1\right)100 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

Thus, the maximum (and minimum) values of E_r and E_θ are exactly the same, but their distributions are different. If the thickness of the plate is assumed to remain the same as before drawing, then the radial strain distribution would be linear, and would appear as shown dotted in Figure 2(b). The difference between the two curves is at once apparent.

Average Radial Strain

Let E_A denote the average radial strain, which is actually given by:—

$$E_A = \frac{\displaystyle\int_{R_1}^{nR_1}\left\{\left(\frac{R_1}{R}\right)\left[\frac{2R - K}{2R_1 - K}\right]^{\frac{3}{2}} - 1\right\}dR}{R_1(n - 1)} \quad . \quad . \quad . \quad (23)$$

Since K is a variable quantity for the integral being considered, it must be replaced by $(nR_1 - R)$, so that

$$R_1\,(n - 1)\,E_A = \int_{R_1}^{nR_1}\left\{\left(\frac{R_1}{R}\right)\left[\frac{3R - nR_1}{R + R_1\,(2 - n)}\right]^{\frac{3}{2}} - 1\right\}dR$$

Putting $P = \frac{nR_1}{3}$ and $Q = R_1 (2 - n)$

$$\therefore R_1 (n-1) E_A = 3\sqrt{3} R_1 \left\{ \int_{R_1}^{nR_1} \frac{1}{R} \left[\frac{R-P}{R+Q} \right]^{\frac{3}{2}} \right\} dR - \int_{R_1}^{nR_1} dR \quad (24)$$

The first integral may be solved by the substitution

$$u^2 = \frac{R-P}{R+Q} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

The solution resulting from equation (24) is:—

$$E_A = \frac{3\sqrt{3}}{(n-1)} \log_e \left[0{\cdot}2679 \left(\frac{\sqrt{3} + \sqrt{n}}{\sqrt{3} - \sqrt{n}} \right) \right] + \frac{4(3-n)(1-\sqrt{n})}{(2-n)(n-1)}$$
$$+ \frac{2}{(n-1)} \left[\frac{n}{2-n} \right]^{\frac{3}{2}} \left\{ \tan^{-1} \sqrt{(2-n)} - \tan^{-1} \sqrt{\left(\frac{2}{n} - 1 \right)} \right\} - 1 \quad (26)$$

Taking the range of $1{\cdot}1 < n < 1{\cdot}7$ (*i.e.*, $\frac{R_B}{R_1} = n$), the following results were calculated for the purposes of plotting the average strain curve shown in Figure 4.

n	E_A
1·1	3·1%
1·2	6·9%
1·3	8·3%
1·4	11·2%
1·5	14·7%
1·6	18·5%
1·7	21·8%

Strain Hardening Factor

Since the flow stress will increase with strain, it was thought reasonable to assume a criterion of flow:

$$\widehat{rr} - \widehat{\theta\theta} = f_0 + \lambda \left(\frac{R}{R_1} - 1 \right) \quad . \quad . \quad . \quad . \quad . \quad (27)$$

Where λ is an arbitrary constant. The justification for this assumption is dependent upon the fact that the strain increases with R, and the introduction of the strain term as a function of R directly is naturally very approximate. The solution obtained for E_r (%) from this criterion is:—

$$E_r^{(\%)} = \left\{ \left(\frac{R_1}{R} \right) \left[\frac{2R - K}{2R_1 - K} \right]^{\frac{3}{2}\left(1 + \frac{\lambda K}{2R_1 f_0} \right)} - 1 \right\} \left[e^p \right] \times 100 \quad (28)$$

$$\text{Where } p = \frac{3\lambda}{2R_1 f_0}(R - R_1) \quad . \quad . \quad . \quad . \quad . \quad . \quad (29)$$

If $\lambda = O$, equation (28) reduces to the original one, namely, equation (19). However, the characteristics of equation (28) were found to be the same as those for equation (19) except that the numerical values of the maximum ordinates were decreased.

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[2]SWIFT, H. W. *Sheet Metal Industries Journal*, Sept., 1943, pp. 1551 and 1548. *Ibid.* June, 1943, p. 996.

[3]NADAI, A. "Plasticity" (Engineering Society Monographs, published by McGraw-Hill), Chapter 34, p. 227.

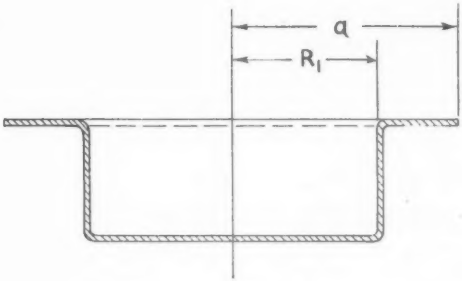


Fig. 1.

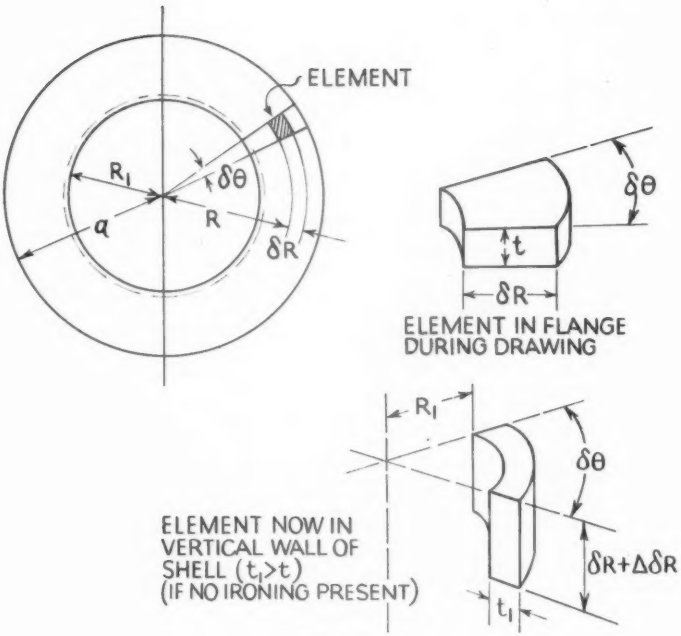


Fig. 2. (a)

% STRAIN

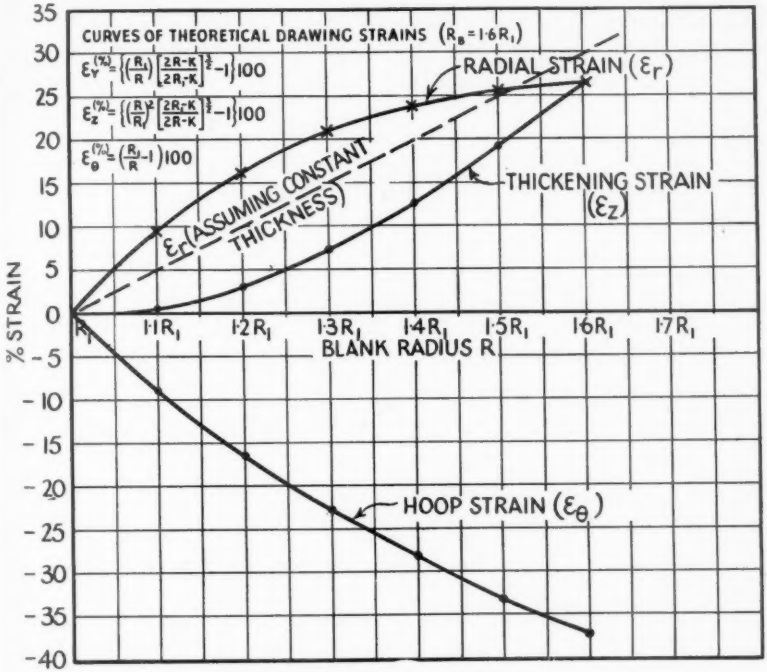

CURVES OF THEORETICAL DRAWING STRAINS ($R_B = 1{\cdot}6R_1$)
$\varepsilon_r^{(\%)} = \left[\left(\frac{R_1}{R}\right)\left[\frac{2R-K}{2R_1-K}\right]^{\frac{1}{2}} - 1\right]100$
$\varepsilon_z^{(\%)} = \left[\left(\frac{R}{R_1}\right)^2\left[\frac{2R_1-K}{2R-K}\right]^{\frac{1}{2}} - 1\right]100$
$\varepsilon_\theta^{(\%)} = \left[\left(\frac{R_1}{R}\right) - 1\right]100$
RADIAL STRAIN (ε_r)
ε_r (ASSUMING CONSTANT THICKNESS)
THICKENING STRAIN (ε_z)
HOOP STRAIN (ε_θ)
% STRAIN
BLANK RADIUS R
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
R_1
$1{\cdot}1R_1$
$1{\cdot}2R_1$
$1{\cdot}3R_1$
$1{\cdot}4R_1$
$1{\cdot}5R_1$
$1{\cdot}6R_1$
$1{\cdot}7R_1$

Fig. 2. (b)

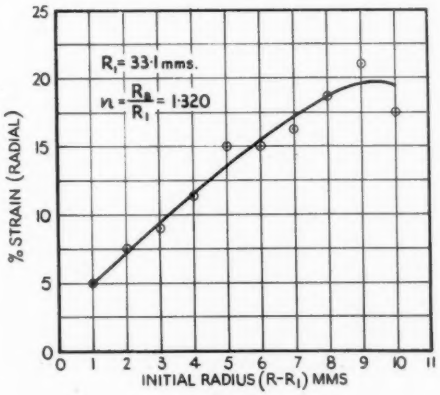

$R_1 = 33{\cdot}1$ mms.
$n_1 = \frac{R_B}{R_1} = 1{\cdot}320$
% STRAIN (RADIAL)
INITIAL RADIUS $(R-R_1)$ MMS
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9 10 11

Fig. 3. (a)

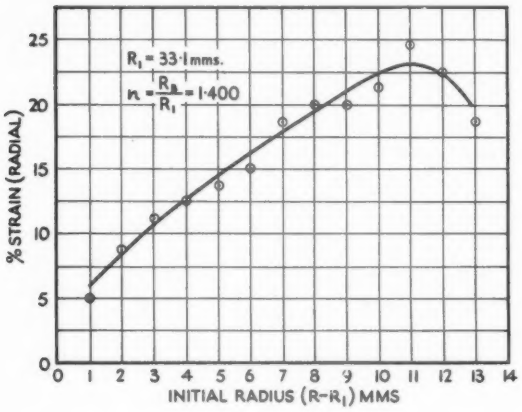

$R_1 = 33{\cdot}1$mms.
$n = \frac{R_2}{R_1} = 1{\cdot}400$
% STRAIN (RADIAL)
INITIAL RADIUS $(R-R_1)$ MMS
0 5 10 15 20 25
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Fig 3. (b)

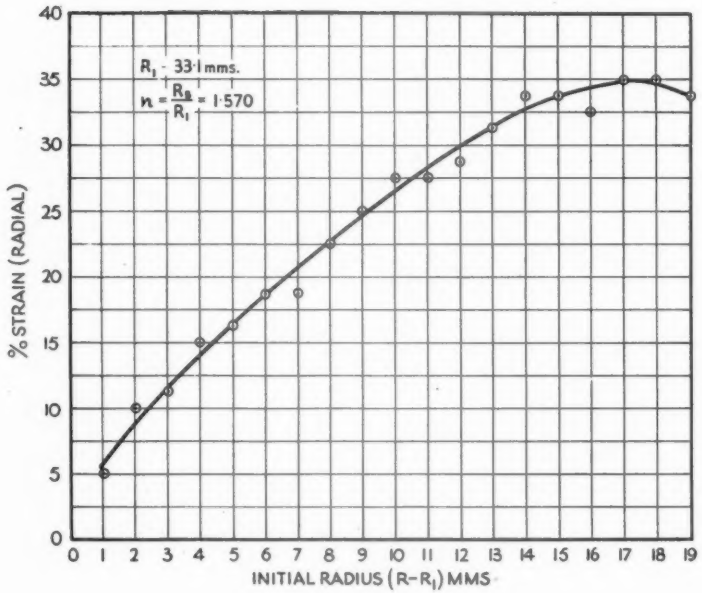

$R_1 = 33{\cdot}1$mms.
$n = \frac{R_2}{R_1} = 1{\cdot}570$
% STRAIN (RADIAL)
INITIAL RADIUS $(R-R_1)$ MMS
0 5 10 15 20 25 30 35 40
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

Fig. 3. (c)

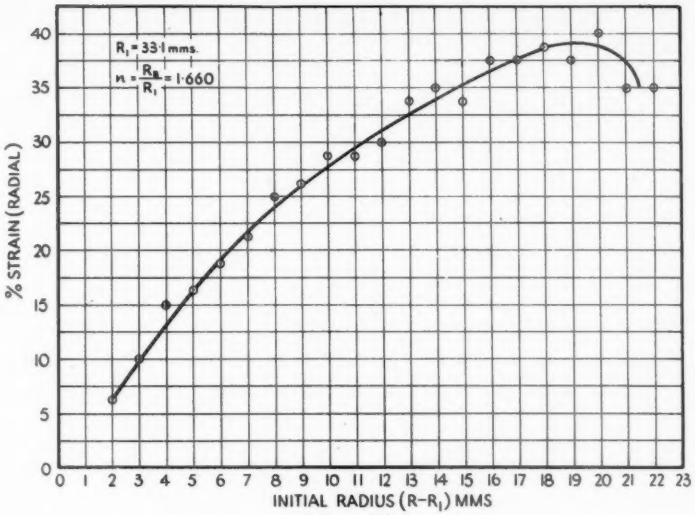

R_1 = 33·1 mms.
$n = \frac{R_2}{R_1}$ = 1·660
% STRAIN (RADIAL)
INITIAL RADIUS (R–R_1) MMS

Fig. 3. (d)

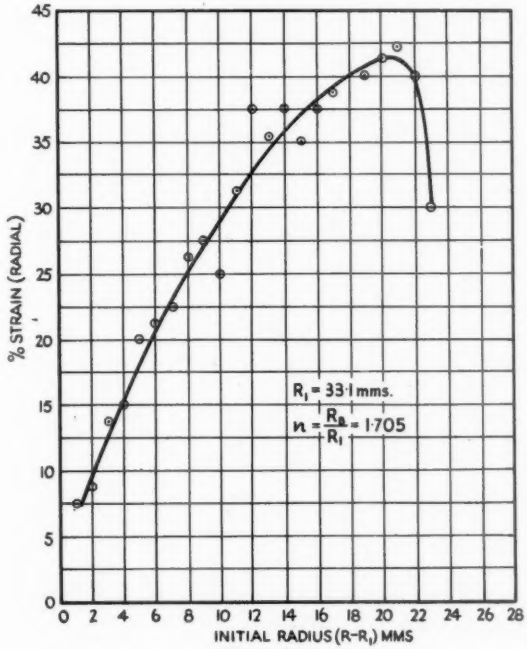

R_1 = 33·1 mms.
$n = \frac{R_2}{R_1}$ = 1·705
% STRAIN (RADIAL)
INITIAL RADIUS (R–R_1) MMS

Fig. 3. (e)

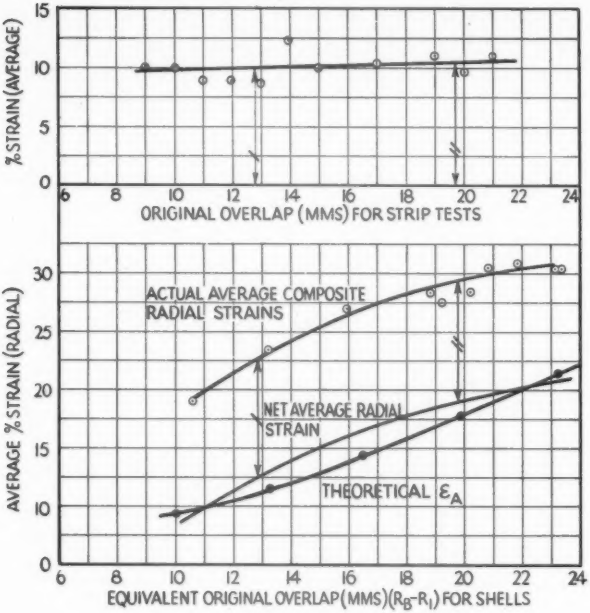

% STRAIN (AVERAGE)
ORIGINAL OVERLAP (MMS) FOR STRIP TESTS
AVERAGE % STRAIN (RADIAL)
ACTUAL AVERAGE COMPOSITE RADIAL STRAINS
NET AVERAGE RADIAL STRAIN
THEORETICAL ε_A
EQUIVALENT ORIGINAL OVERLAP (MMS) $(R_B - R_1)$ FOR SHELLS

Fig. 4.

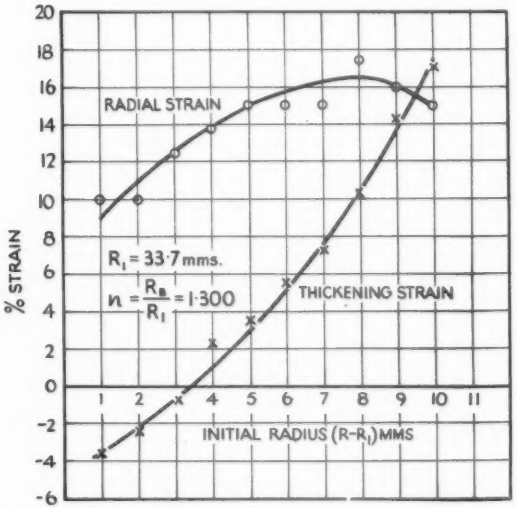

RADIAL STRAIN
% STRAIN
$R_1 = 33{\cdot}7$ mms.
$n = \frac{R_B}{R_1} = 1{\cdot}300$
THICKENING STRAIN
INITIAL RADIUS $(R - R_1)$ MMS

Fig. 5. (a)

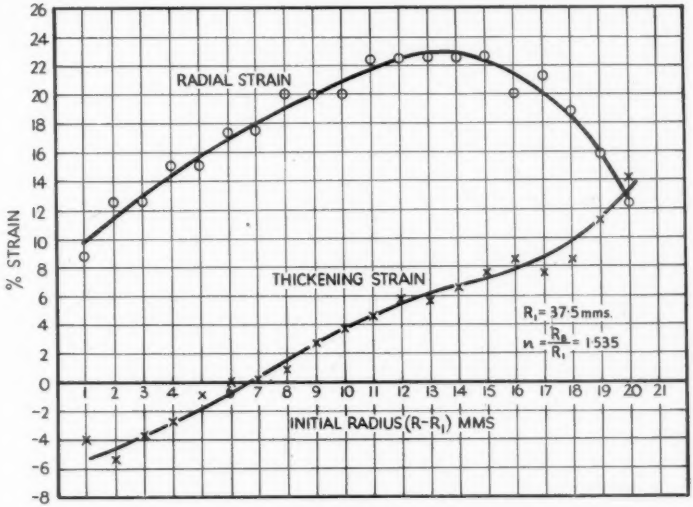

RADIAL STRAIN
THICKENING STRAIN
R_1= 37·5mms.
$n = \frac{R_2}{R_1}$ = 1·535
% STRAIN
INITIAL RADIUS (R-R_1) MMS

Fig. 5. (b)

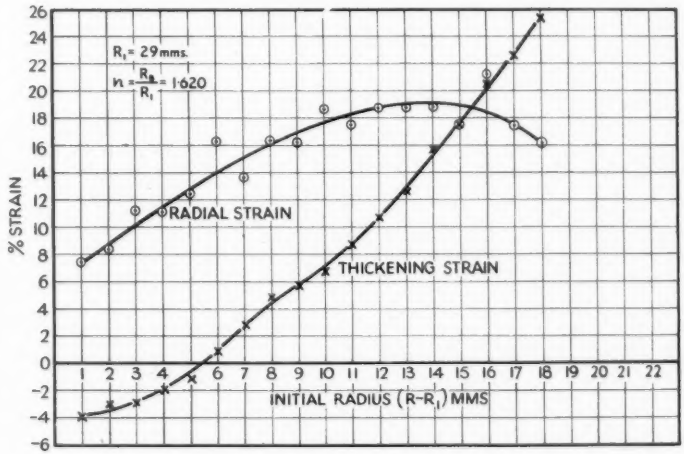
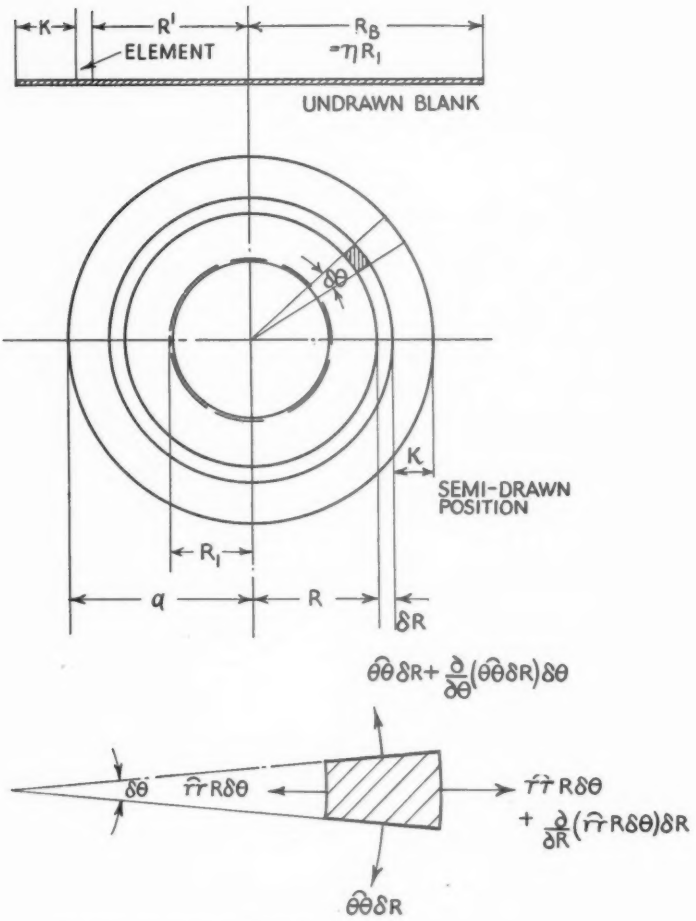

R_1= 29mms.
$n = \frac{R_2}{R_1}$ = 1·620
RADIAL STRAIN
THICKENING STRAIN
% STRAIN
INITIAL RADIUS (R-R_1) MMS

Fig. 5. (c)



FORCES ON ELEMENT DURING DRAWING

Fig. 6.

THE METALLURGICAL ASPECTS OF THE MACHINABILITY OF STEEL

by L. W. JOHNSON, M.Met., M.I.Mech E., M.I.P.E.

Presented to the Wolverhampton Section of the Institution, May 12th, 1948.

A perusal of the " Bibliography on Cutting of Metals ", edited by O. W. Boston (1), shows that it lists some 4,124 references so that it cannot be said that the subject of machinability has by any means been neglected. Nevertheless, in studying the literature conflicting statements are encountered concerning the performances of different tools or the relative machinability of different materials. This has most probably been due in many instances to the possibility that conditions have not been truly comparable, and this is not to be wondered at when consideration is given to the large number of variables which exert considerable influence on the problem. These are :—

(*a*) The type of cutting tool used, its shape, composition, hardness, as well as its surface finish.
(*b*) The speeds and feeds.
(*c*) The capacity, rigidity and condition of the machine tool, with special reference to the tool holder.
(*d*) The coolant or lubricant.
(*e*) The type of finish.
(*f*) The size of the component being machined.
(*g*) The metallurgical condition of the material to be machined.

As a considerable amount of data is available concerning items (*a*) to (*f*) in the form of machining recommendations issued by the manufacturers of both metals and machine tools, as well as articles in the technical press, it is proposed to confine this lecture to item (*g*) and, in particular, to the subject of steels. This section is subject to further variables which can be summarised as follows :—

(*a*) General physical condition, *i.e.*, cast, wrought, cold worked, etc.
(*b*) Chemical composition.
(*c*) Type of micro-structure, with which is associated heat treatment.
(*d*) Grain size.
(*e*) Non-metallic inclusions.
(*f*) Surface condition.
(*g*) Mechanical properties.

It is hoped that a brief survey of these variables will firstly be helpful in throwing some light on anomalies which have been en-

countered in the past and secondly, emphasise that in recent years considerable attention has been given to the relation between micro-structure and machinability, thereby providing the production engineer with the means to achieve better control.

RELATION OF PRODUCTION TO DESIGN REQUIREMENTS

The ideal steel, as far as the production engineer is concerned, is one which enables him to remove the surplus material in the least time with the minimum of power consumption, minimum wear and tear on both the cutting tools and the machine tools, with which may also be associated the production of a specified finish. This usually means a steel of low tensile strength which is lacking in ductility and toughness as revealed by elongation and reduction of area per cent in the tensile test, and by the impact value in ft. lb. in the Izod test respectively. This type of steel, unfortunately for the production engineer, does not generally find a place in the schedule of the designer who, more often than not in these days of progress, must employ not only steels with high tensile strength, but also with high toughness values. This incompatibility of requirements is not, however, insurmountable for as will be seen later, the situation can be considerably relieved by suitable heat treatment.

Surface finish is in itself important, not only because of appearance, but also because torn surfaces can act :—

(*a*) as focal points for the acceleration of corrosion, and

(*b*) as stress raisers in steels (especially the higher tensile) when subject to fatigue conditions in service.

Incidentally, torn surfaces may act as crack formers in the heat treatment of tool steels and the like.

TYPES OF STEELS

There is now available to the engineer a very large number of different types of steels which are given an equally wide range of physical properties by modifications in chemical composition, in heat treatment and in mechanical treatment. They can be conveniently placed into broad groups as follows :—

A. Carbon steels.

B. Low and medium alloy steels.

C. Corrosion-resisting and heat-resisting steels.

D. Special purpose steels.

The steels in group B include case-hardening steels which may have a core strength up to about 90 tons per square inch tensile strength, and direct-hardening steels up to 110 tons per square inch and over, which thus in themselves constitute a considerable problem in machining.

Steels of the austenitic type are included in group C and although they have medium tensile strengths they present certain machining problems of their own.

Steels in group D comprise tool steels as well as steels having special expansion, magnetic or other physical properties.

TYPES OF STRUCTURE

The microstructure of a steel has an important bearing on its machinability, and recent work has tended to show that taking into account the two variables of the actual machining operation, and the type of steel, there is an optimum structure which can be employed. The structure of a steel depends on its chemical composition, its method of manufacture and its heat treatment, but before dealing with these aspects it may be advisable to refer briefly to the different types of microstructure such as ferrite, pearlite, spheroidised cementite, sorbite, martensite and austenite which are encountered in machining.

In the first place, carbon steel consists essentially of pure iron (or ferrite) and iron carbide (or cementite). In the normalised or fully annealed condition, a eutectoid of ferrite and cementite is formed, consisting of alternate thin plates of lamellae of these two constituents. This is known as lamellar pearlite and the carbon content of the pearlite is of the order of 0.8%. Thus in a steel containing say 0.2% carbon, 25% of the structure will be pearlite and the remainder ferrite, and the relative proportion of ferrite to pearlite will vary according to the carbon content up to 0.8%. The hardness also increases with the carbon content. Above 0.8% excess cementite will be present, and this will separate either as globules or as a network at the grain boundaries.

When the steel is heated at a temperature in the vicinity of the critical temperature, the lamellae of cementite become globular or spheroidised in a matrix of ferrite, and the treatment is known as spheroidising. The term "spheroidised pearlite" has been used to describe this constituent, but is not really correct since this structure can also be produced from an initial structure of martensite. The term "spheroidite" is sometimes used, but in this lecture it will be referred to as spheroidised cementite.

When steel is heated above its critical point and quenched in a suitable medium, a hard constituent known as martensite is formed, and on subsequent tempering this breaks down into sorbite, which is a finely divided, almost emulsified, distribution of the carbides and has a granular appearance. As the result of further tempering or higher tempering temperatures, it assumes the form of fine globular carbides. This structure, however, should not be confused with the much coarser spheroidised cementite referred to previously. Fig. 1 illustrates the four types of structure.

So far plain carbon steels have been considered, and the addition

of alloying elements may only slightly or greatly affect the structures described, according to the amounts added. As is known, when steel is heated above the critical points the various constituents are taken into solid solution and austenite is formed. When carbon steels are cooled through the change point, the austenite breaks down and according to the rate of cooling hard martensite or pearlite may be produced. Incidentally, mention should be made of intermediate product or bainite which is produced when the quenching rate is not sufficiently rapid to ensure the formation of martensite. This constituent is not as hard as martensite, and when tempered provides inferior mechanical properties. In order to produce martensite a minimum rate of cooling, known as the critical cooling velocity, must be exceeded and certain alloying elements such as manganese, nickel, chromium, and molybdenum, by rendering the changes progressively more sluggish, have the power of reducing this velocity so that oil quenching or even cooling in air will suffice to harden the steel. On further additions of the elements, particularly manganese and nickel, being made, the austenite remains stable at room or sub-zero temperatures, and as examples may be quoted the well known 12% manganese steel and the 18/8 chromium-nickel corrosion-resisting steel.

Having briefly discussed the mode of formation of these structures, it will be of interest to consider their properties and relation to machinability :—

(*a*) *Ferrite* is a soft, ductile and low tensile strength material. It has a tendency to produce a large built-up edge and the chip clings to the tool without breaking away readily. This, coupled with the fact that ferrite tears away from the surface of the material being machined, results in a rough surface. Excessive frictional heat is also developed.

(*b*) *Pearlite* in the lamellar form consists of alternate thin plates of hard, brittle cementite and soft ferrite. The former reinforces the latter, thus providing a rigid structure which permits easier cutting than of the ferrite, but which consumes considerable energy in cutting. The cementite, which is in any case too hard to be cut by steel tools, will cause wear of the tool.

(*c*) *Spheroidised Cementite* exists in the form of globules or spheroids of cementite in a matrix of ferrite. It is probable that these globules are not cut through as they are too small to render this necessary as the tool progresses through the ferrite. The cementite globules do, however, provide some support to the ferrite but not to the same extent as is the case with the lamellae or plates of cementite. The wear on the tool will increase with the increase in the size of the globules of cementite.

(*d*) *Sorbite* is the result of tempering martensite, and according to the tempering temperature is relatively hard and ductile, which

conditions, while they are not usually desirable as far as some machining operations are concerned, are nevertheless satisfactory in others. However, bars, forgings, etc., are often required to be machined in the fully heat treated conditions, and while to some extent the machinability of sorbite varies inversely with the hardness, this is not necessarily the case at the lower tensile levels where high impact values may be obtained in alloy steels.

(*e*) *Martensite* is encountered in fully hardened steels and its hardness and ductility vary according to the carbon and the alloy contents. Machining is not easy and cemented carbide tools will be necessary for most conditions. Traces of martensite may also be present in alloy steels due to an incorrect annealing treatment, and will thus be an unsuspected cause of machining trouble. Study of the " S " curves will enable the correct treatment to be ascertained in such a case.

(*f*) *Austenite* usually has moderate tensile strength and excellent ductility and toughness, coupled with a high capacity for work hardening. This combination of factors renders machining difficult due to the production of continuous chips which, because of the high pressures generated at the cutting edge, tend to clog and adhere to it.

CARBON STEELS As has been noted previously, ferrite is not a desirable constituent when present in any quantity, and consequently low carbon steels are not particularly easy to machine, resulting as they do in a rough, torn surface. Improvements can be effected by the use of controlled amounts of added elements such as lead, sulphur, phosphorus and selenium, and also by cold work. The latter reduces the ductility of the ferrite; lead acts mainly as a lubricant and the others as chip breakers, although sulphur and selenium may also have some effect from the anti-galling aspect. As far as heat treatment is concerned, low carbon steels generally machine better when normalised.

Better machinability is found in the carbon range 0.30 to 0.45% but above this amount the increasing content of pearlite increases the hardness so that machining becomes more difficult. At these higher carbon levels, improvement can be achieved by reducing the hardness by partial spheroidisation and at about 0.9% carbon it should be almost complete.

LOW AND MEDIUM ALLOY STEELS In recent years considerable attention has been devoted to the correlation of heat treatment and structure in ensuring improved machinability of alloy steels. Before reviewing the technical literature on this particular aspect, some reference should be made to the actual methods of heat treatment. Generally speaking, it was at one time the practice, according to the type of steel, to employ a treatment

that was relatively simple and consisted either of normalising followed by cooling in air, or annealing followed by relatively slow cooling or by quenching and tempering. However, the advent of " S " curves (isothermal transformation diagrams or a time-temperature-transformation or T-T-T diagrams) enables a much better grasp of the potentialities of the controlled cooling of steels to be obtained.

Briefly, the " S " curves show in relation to temperature and time the transformation of austenite at any constant temperature below that at which it ceases to be stable. The time which elapses at any given temperature before austenite commences to break down, and also the duration of time required for the transformation to be completed, varies very considerably, not only at different temperature levels, but also for different types of steels. The " S " curves also usually give some indication of the hardness of the resulting product. Isothermal or constant temperature heat treatment is of considerable assistance in providing improved machinability for the more highly alloyed steels.

H. B. Knowlton (2) in a survey of the technical literature provides the following data :—

(*a*) *Low carbon steels for carburising.* Forged gear blanks should be normalised or annealed before machining, depending on the composition of the steel. Generally speaking, the lower alloy steels will machine better after normalising. Some of the higher alloy steels such as 3% nickel SAE.2315, and 5% nickel SAE.2512, may require slower cooling in order to produce the desired Brinell hardness which should be of the order of 170 to 200 for most operations, although for broaching, 200 is to be preferred rather than 170.

Microstructure is stated to play an important part in the machinability of these steels and Fig. 2 shows that the 2% nickel-molybdenum steel SAE.4615 normalised to produce a coarse Widmanstätten structure permitted nearly double the rate of production obtainable with a fine banded structure.

There may be a limit, however, to the utilisation of coarse grain size for machinability, particularly when it is duplex or of variable grain size, as this may lead to distortion in subsequent hardening. Consequently, it is recommended that for gear blanks and similar parts, where minimum distortion is essential, the normalising temperature should not exceed 925°C.

(*b*) *Medium carbon heat treating steels.* As a general rule structures produced by drop forging are too coarse and the hardness may be frequently too high for good machining. In considering the 0.45% carbon type of alloy gear steels, *e.g.*, 3½% nickel SAE.2350, 1¼% nickel-chromium steel, SAE.3145, 1% chromium-molybdenum steel, SAE.4150, 1% chromium steel, SAE.5150, etc., Knowlton

refers to Woldman's preference for a spheroidised structure for automatic machining operations and a lamellar structure for broaching and hobbing.

Where only one annealing treatment is used, the lamellar structure is generally preferred. Annealing is frequently carried out in cycle annealing furnaces in which the steel is first heated to the normalising temperature and then dropped to a lower temperature and cooled slowly until transformations are complete. This process can be controlled to provide either spheroidal or lamellar structures.

Incidentally, banded structures are stated to be undesirable for medium carbon alloy steels as well as all other steels except screw stock and very low carbon steels. On the other hand, N. E. Woldman (10) whilst stating that the tearing of free ferrite will not be so great in alloy case-hardening steels as in plain carbon case-hardening steels, nevertheless considers machining troubles with the banded structure will be noticeable in light cutting, drilling, tapping, thread cutting (especially chasing), reaming and broaching.

(*c*) *High carbon alloy steels.* The high carbon-chromium ball-bearing steel such as SAE.52100 is given as an example of a steel in this category which is difficult to machine. It must be carefully annealed not only for machinability, but also to produce a structure which will harden satisfactorily without brittleness. A spheroidised structure is usually considered to be the best for both these purposes, although some investigators prefer a small amount of lamellar pearlite also to be present from the machining aspect.

A. H. d'Arcambal and W. E. Bancroft (3) refer to the desirability, when producing tool steels for machining, of processing the steel so that the carbide particles are small and uniform in size and distributed as uniformly as possible throughout the matrix. As cementite has a hardness of over 900 D.P.H., the proper distribution is important. It has been found that the smaller the spheroids the smoother the surface which will be obtainable, and also that the lamellar structure containing networks is distinctly undesirable from a hardening standpoint, resulting in cutting tools having a high degree of brittleness.

The above authors also show the effect of two types of heat treatment on a tap blank made from carbon-vanadium tool steel when threaded in a die head. The surface finish and the microstructure are shown in Figs. 5 and 6. The unsatisfactory treatment consisted of spheroidising and cold-drawing (which, incidentally, is entirely satisfactory for turning, milling, reaming and milling) and the improved treatment was obtained by heating the tap blanks prior to the threading operation in a lead pot at 800°C., followed by cooling in an air blast. This resulted in a partially sorbitic structure which was also slightly harder. Incidentally, when trouble is encountered in machining the unhardened carburised case of alloy

case-hardening steels this may be due to partial air-hardening, and can be overcome by tempering at 625/650°C. Abnormality (10) in the form of divorced pearlite and massive segregated carbide areas and ferrite may also be a cause.

P. Payson (4) has adopted the use of isothermal decomposition in providing a method for softening alloy steels which resist spheroidisation and which therefore results in a considerable saving in time compared with the older methods of annealing. The process consists of austenitising the steel at a temperature of from 5 to 85°C. above its Ac_1 temperature and then cooling as rapidly as practicable to a temperature 5 to 85°C. below the Ac_1 temperature and holding for a sufficient length of time to complete the transformation. Payson recommends that in the case of some alloy steels the steel should be heated just below the critical range for a period of time prior to the austenitising, which causes the carbides in the original structure to agglomerate, so that when the steel is subsequently austenitised, the enlarged carbides do not dissolve so readily and serve as the nuclei for the formation of coarse spheroidal carbides when the austenite transforms. As an example, the treatment given to a SAE.4340 steel (1¾% nickel-chromium-molybdenum) consisted of preheating for two hours at 690°C., then austenitising at 740°C. for one hour followed by isothermal transformation at 650°C. for four hours. The resulting Brinell hardness was 197. (5)

G. R. Brophy (6) has shown that a normalising treatment will serve the same purpose as the preheating and is sometimes more effective.

Reference has been made earlier to the undesirability of banding, since the longitudinal streaks of ferrite so formed result in a poor surface and tool chatter. Banding of the ferrite is likely to result when the cooling is slow, and it is preferable to cool relatively rapidly to well below the Ac_1 temperature and to avoid transformation too near to this, *e.g.*, the 3% nickel-chromium case-hardening steel SAE.3312, if it has a tendency to banding, will be more inclined to do so when transformed at 650°C. than at 590°C.

In passing, it may be mentioned that in the annealing of steels the austenitising temperature has an influence on the product, that is the nearer the austenitising temperature is to the Ac_1 temperature the greater the tendency to form a spheroidised structure on subsequent isothermal transformation, and also the higher the temperature the greater the tendency to form lamellar pearlite, which will have a lower reduction of area in the tensile test and better machinability in many operations.

G. P. Witteman (7) has provided data covering different forms of machining in relation to various broad groups of alloy steels and structure and Table A is based on his work. Table B gives an indication of the treatments which will produce these structures.

K. J. B. Wolfe (8) has published a comprehensive report covering machining tests, especially from the point of view of gear cutting, which he carried out on a variety of carbon and alloy steels. He confined his work to the hardened and tempered condition because of the necessity of ensuring complete absence of distortion, which heat treatment subsequent to gear cutting would not do. He found that in this condition, considerable improvement in the machinability could be obtained by employing a second tempering at a temperature 25°C. lower than the initial one, and followed by oil quenching.

TABLE A

Relative Machinability of Alloy Steel as Related to Structure and Carbon Content

Carbon Range	*Type of Conditioning Heat Treatment*	*Type of Structure*	*Relative Machinability in :—*			
			Turning	*Forming*	*Drilling*	*Broaching and Gear Generation*
Low (0.08–0.30%)	Normalise and/or Anneal	Lamellar Pearlite with Blocky Ferrite	Good	Good	Good	Good
	Quench and Temper*	Sorbite (fine spheroidised)	Good	Good	Good	Good
Medium (0.30–0.50%)	Anneal	Coarse spheroidised	Good	Poor	Fair	Poor
	Anneal	Lamellar Pearlite	Fair	Good	Good	Good
	Quench and Temper	Sorbite (fine spheroidised)	Fair	Fair	Fair	Fair
High (0.50–0.70%)	Anneal	Coarse spheroidised	Good	Good	Good	Fair
	Anneal	Lamellar Pearlite	Fair	Poor	Poor	Fair
	Quench and Temper	Sorbite (fine spheroidised)	Good	Fair	Good	Good

* This treatment is rarely applied to low carbon bar stock, but is frequently used to condition forgings.

TABLE B

Representative Conditioning Treatments for Low and Medium Carbon Alloy Steels

Type of Treatment	*Details of Treatment*				*Final Structure*
	Operation	*Time, hours*	*Temp., °C.*		
			0.15% carbon	*0.45% carbon*	
Simple Anneal	Furnace cool after	1	870	815	Lamellar Pearlite plus Ferrite
Quench and Temper	Oil quench after	1	870	815	Sorbite (fine spheroidised)
	Temper ...	2	675	675	
Isothermal Anneal	Normalise ...	1	860	790	Coarse Spheroidised
	Austenitise ...	1	815	730	
	Transform ...	10	660	660	

N. E. Woldman (9) refers to a questionnaire he issued to various plants in the U.S.A. requesting their experience in the machining of three types of gear steels, *i.e.*, 1% chromium-vanadium SAE.6150, 1¾% nickel-chromium SAE.3250 and 1¾% nickel-chromium-molybdenum SAE.4350. The replies showed that the heat treatment practice varied widely from plant to plant, and so he decided to carry out tests in order to establish the relationship between the microstructure and machinability in these three steels. The details of this work are given in Appendix 1.

The same author (10) has also described standard structure sheets showing the type of structure which is acceptable for machining. In Fig. 7 is reproduced a chart relating to 1¼% nickel-chromium-steel SAE.3135 normalised and annealed, and the following information is given relating to the different structures :—

A. is the desired structure for all operations including gear cutting, threading, etc.
B. which has a fine grain size will give an excellent surface but less pieces per grind of tool, owing to more heat being generated.
C. if the duplex structure is strongly marked it is undesirable—it will also produce more distortion in hardening.
D. this banded structure is undesirable although very slight banding would be acceptable.
E. the coarse grain will give trouble due to large pearlite and ferrite areas, and also distortion will be more pronounced in hardening.

F. this spheroidised structure is undesirable in all operations except roughing operations in automatic screw machines. In taking light cuts, threadings, gear cuttings, etc., a rough surface will be obtained.

As is the case with carbon steels, the addition of lead to alloy steels results in a marked improvement in machining. As high sulphur (11) additions bring about a lowering of the ductility and fatigue strength of steel, care should be exercised in using sulphur-treated alloy steels for applications which involve highly stressed components.

CORROSION-RESISTING AND HEAT-RESISTING STEELS

There are three main types of corrosion-resisting steels, that is the pearlitic, the martensitic and the austenitic. The true ferritic stainless steels are those which because of their high chromium content (usually above 17%) and low carbon content (0.12% maximum) are essentially non-responsive to hardening by quenching. They have a tensile strength in the annealed condition of about 35 tons per square inch.

The martensitic steels can be divided into :—

(*a*) The 11–14% chromium steels and

(*b*) The 14–18% chromium steels with 1–3% nickel.

The tensile properties of these steels depend on the heat treatment and composition, and in particular the carbon content, but are generally used for engineering purposes in the tensile range 35/65 tons per square inch, as in the En.56 and En.57 or S.61, S.62 and S.80 specifications.

Of these grades the ferritic type is more easily machined, but in the martensitic group the chromium-nickel steels such as S.80 have the better machining properties. Some of the steels in group (*a*) at the higher carbon levels can be heat-treated to have tensile strengths up to 100 tons per square inch and over, and it is therefore advisable for tensile strengths above say 65 to machine as far as possible in the annealed condition.

The austenitic steels, such as the well-known 18/8 chromium-nickel steel, are more difficult to machine as they are very ductile and work-harden considerably. These steels cannot be hardened by the usual quenching method, in fact, rapid cooling from say 1100°C. softens them, and apart from the recently developed precipitation hardening type can only be hardened by means of cold work. This type may have variations in the nickel and chromium contents and also contain one or more of the other alloying elements such as molybdenum, tungsten and copper, as well as titanium and niobium (columbium). The latter two elements are added to stabilise the steel against intergranular corrosion or " weld decay " when heated in the range 450 to 800°C.

Improvement in machinability is obtained by additions of one or more of sulphur, selenium, zirconium, phosphorus, lead, silver, etc. Sulphur or selenium additions are usually of the order of 0.15–0.20%, and in some cases are also in association with molybdenum and zirconium, which may be about 0.4 and 0.2% respectively. C. Sykes (11) reports that such additions, whilst improving the machinability in such operations as turning, result also in very great improvements in sawing, drilling, etc. He concludes, therefore, that this indicates that the machining difficulties of austenitic steels are due, not so much to their work-hardening capacity but to difficulties associated with the rapid elimination of the chips from the working face of the tool.

H. B. Knowlton (2) refers to the use of heat treatment in effecting improvement in machining the normal 18/8 type. This consists of annealing at 800/900°C. which causes precipitation of carbide particles at the grain boundaries, and the chips thereby to break off short. This treatment only applies to the unstabilised type and obviously it is absolutely essential that the steel shall be " restored " after by heating to about 1100°C., followed by quenching in order to ensure satisfactory corrosion resistance in service.

Heat-resisting steels consist of either (*a*) the straight chromium type containing up to about 30% chromium and up to say 1% carbon, or (*b*) the austenitic chromium-nickel type which may contain up to 25 and 35% chromium and nickel respectively in association with small additions of silicon, tungsten, molybdenum, etc. The machinability is of the same order as for the similar types of corrosion-resisting steels, attention being paid, of course, to the higher carbon straight chromium type in which, however, the carbides are present more or less in the spheroidised condition and therefore would be expected to behave somewhat similarly to the high carbon tool steels.

SPECIAL STEELS Tool steels which have been included in this category range from the plain carbon type to quite complex chemical compositions of the high speed type. The presence of complex carbides is usually associated with the more highly alloyed types, and consequently it is important to ensure that these carbides are evenly distributed, avoiding segregation such as occurs in the form of streaks of relatively massive particles, or as network.

As is the case with the low and medium alloy steels, Brinell hardness is not *per se* a reliable guide to the machinability of these steels. The high carbon type of steel with small amounts of alloying elements has already been referred to in the low and medium alloy steel section. In general, it has been found that the smaller the size of the cementite spheroids of the annealed steel, the smoother will be the finish. Some workers prefer small amounts of lamellar

pearlite to be present, say up to 25%, but it is rather difficult to ensure this consistently. Incidentally, it is stated (3) when the lamellar pearlite structure contains networks it is unsatisfactory from the hardening point of view, as it tends to produce brittleness in the steel.

F. R. Bonte (13, 14) in an article dealing with the tool and die uses of graphitic steels containing about 1.5% carbon, states that these steels have free machining properties in the annealed state obtained by normalising in the case of a 1¾% nickel-chromium-molybdenum composition at 960°C., followed by reheating to 780°C., and cooling to 680°C. at 6°C. per hour, then furnace cooling to 480°C. This resulted in a Brinell hardness of 228/241.

Appropriate annealing treatments are supplied by the makers of high-speed steels and usually consist of careful heating up to 850/870°C. soaking, followed by slow cooling resulting in a Brinell hardness of 200–280 according to the actual composition, the higher hardness values being associated with the higher cobalt contents. This should produce finely divided carbides evenly distributed throughout the matrix.

Other types of special steels which may be encountered will usually be found to fit into one or other of the groups already discussed.

MISCELLANEOUS FACTORS

Non-metallic inclusions, such as sulphides, have been referred to earlier, but it is important that such inclusions shall be relatively soft. Aluminium, which is used for the deoxidisation of steel, and sometimes in relatively large amounts for the production of grain size controlled steel, may be present as hard particles of alumina. If these are present in large clusters as in Fig. 8 they can be very detrimental in causing wear of the tool. Silicates are also hard but manganese oxide, ferrous oxide and sulphides are relatively soft and will, therefore, improve machinability.

Faulty-heat treatment can produce trouble in machining due either to a tenacious scale or to surface carburisation or decarburisation. Also in hardening and tempering it is possible when using a steel which is not sufficiently deep hardening in relation to the diameter, for variations to occur across the section both in hardness and structure. Segregation of elements can also produce a similar state. These aspects should be kept in mind when comparisons are made concerning machinability reported on various materials by different workers.

Reference may also be made here to the effect of increasing the grain size by raising the normalising temperature, which results in improved machinability. Thus in comparing results of tests it is

important to know both the normalising temperature employed as well as the grain size, since some steels resist grain growth at elevated temperatures more than others.

A further source of error in comparing the results of machining tests is the time effect. Thus O. W. Boston (12) referring to the use of Taylor's formula $VT^n=C$ in connection with the machining of $2\frac{1}{4}$ in. diameter bars of 1.75% manganese steel SAE.1340 and 1.25% nickel-chromium steel SAE.3140, both annealed at 860°C. for one hour, points out that the curves cross each other. The following results taken from the curves show how a false deduction can be drawn :—

	Cutting Speed : Feet per Minute	
Tool Life in Minutes	*SAE.1340*	*SAE.3140*
10	120	90
400	40	58

Similarly in comparing the performance of the SAE.1340 steel in the annealed and also the spheroidised conditions, the curves crossed at a tool life of 90 minutes.

Welding may cause some trouble, especially in the case of the higher tensile structural steels, due to hardening at the weld caused by the rapid cooling set up by the quenching effect of the relatively large mass of cold metal. This can usually be overcome by preheating at 200°C. or more prior to welding, and in some cases by suitable post-weld heat treatment, *e.g.*, tempering at 450/650°C. according to the type of steel.

CONCLUSION There are many major variables which affect machinability and considerable attention has been given to them in the technical press as well as in the Proceedings of this Institution. It was considered advisable in this present paper to concentrate on one of these variables—that relating to the metallurgical point of view, and to make a résumé of the literature which has appeared on this particular aspect.

Of the various metallurgical factors which have been discussed, it would appear that the most promising means of improving machinability are controlled heat treatment on the one hand, and the employment of small amounts of metallic and non-metallic elements on the other. Some of the latter may be objectionable from the ultimate use point of view, since they cause a certain deterioration of mechanical properties. Heat treatment is more elastic in its use, since it can in the first place be employed to put the steel into the optimum machining condition which entails a particular type of

structure with which may be associated an enlarged grain size, and in the second place the optimum condition for use in service can easily be restored by further heat treatment.

In practice it may not always be possible to carry out the above ideal treatment, and particulars have been given of the comparative machinability of other structures, so that the production engineer can select a suitable compromise when more than one operation is involved.

The individual effect of alloying elements has not been considered in detail, but alloy steels have been discussed in the state in which they are generally used. In connection with this aspect, E. J. Janitzky (15) has pointed out that " variation in chemical composition does not influence machinability, provided that the steels can be heat-treated to have the same tensile properties. In other words, if two steels are heat-treated to have the same tensile properties (tensile strength, yield stress, elongation and reduction of area) assuming such heat treatment is possible, they will be equal in regard to machinability ". Janitzky particularly stresses the importance of the ratio of the yield stress to the tensile strength, and consequently since Brinell hardness does not provide any clue to this ratio it is not *per se* a reliable guide to machinability. Chemical composition is, therefore, only of importance as far as it affects the attainment of the required structure, and examples have been given of the means of achieving this.

The main object of this paper has been to present to the production engineer the metallurgical variables which can affect machinability with a view to :—

(*a*) explaining some of the anomalies with which he may have been confronted,
(*b*) showing how improvement can be achieved, and
(*c*) stimulating discussion with a view to formulating further research work.

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Appendix 1

*Investigation into the Machinability of Gear Steels**

In order to establish the relationship between machinability and microstructure of gear steels, three $1\frac{3}{4}$ inch diameter bars of each of three electric furnace steels, that is SAE.3250, 4350 and 6150 were obtained. Details of the chemical composition and mechanical properties in each of three heat treatments are as follows :

TABLE 1

		SAE.3250			*SAE.4350*			*SAE.6150*		
Carbon	per cent	0.47			0.47			0.50		
Manganese	" "	0.44			0.65			0.59		
Sulphur	" "	0.012			0.020			0.016		
Phosphorus	" "	0.017			0.015			0.018		
Nickel	" "	1.81			1.80			—		
Chromium	" "	1.00			0.84			0.95		
Molybdenum	" "	—			0.20			—		
Vanadium	" "	—			—			0.19		
Heat Treatment		*A.*	*S.*	*Q.*	*A.*	*S.*	*Q.*	*A.*	*S.*	*Q.*
Yield Point t.s.i.	...	23.0	23.4	23.5	24.4	22.0	24.8	19.3	18.4	25.4
Maximum Stress t.s.i.		44.8	39.1	42.1	46.4	44.6	45.2	37.4	35.7	36.0
Elongation % in 2"	...	23.5	31.5	28.5	24.0	26.0	26.2	31.0	33.5	34.5
Reduction of Area %		50.1	62.7	58.6	46.1	50.4	49.9	60.2	63.3	68.1
Brinell Hardness	...	187	183	187	203	185	197	175	156	166

A signifies pearlite-annealed.
S " spheroidise-annealed.
Q " quenched and tempered.

* Abstracted from N. E. Woldman : " Microstructure and Machinability." The Iron Age, June 26, 1941, pp. 44–49.

Details of the types of machining investigated for small aircraft bevel gears (12 teeth ; 8 pitch ; 1500 P.D. ; 1.69 in. o.d.) are as follows, and the particulars of the condition of the respective machined surfaces are given in Table 2.

AUTOMATIC MACHINING

Each bar was machined for one hour in a No. 6 Brown and Sharpe automatic machine with tools set for centre drilling, drilling, forming, counterboring, reaming and cutting off operations. All tools were made from 5% cobalt high speed steel, except the drills which were made from standard high speed tool steel. The spindle speed was set at 343 r.p.m. to produce 12 gear blanks per hour. Eccol-Kut 1-X sulphur base cutting oil was used as the lubricant.

The machinability rating of each bar was obtained from the character of the chips formed from each tool and from the surface appearance of the gear blanks.

The general conclusions for the automatic machining were that of the SAE.3250 steel bars, the quenched and tempered bar machined the best, the spheroidised bar was next in order, and last the annealed bar. The quenched and tempered bar showed softer and longer chips and better curls than the other two bars. The annealed bar machined the poorest, although it was satisfactory. Of the

SAE.4350 steel bars, the quenched and tempered bar machined the best, the spheroidised bar did not machine quite as well, while the annealed bar was the poorest of the three. The quenched and tempered bar appeared softer and more close-grained than the other two bars. The annealed bar appeared harder and tougher than the spheroidised bar. The gear blanks from the annealed bar were hotter than the cut-off blanks from the other two bars. Of the SAE.6150 steel bars the spheroidised bar machined the best, the quenched and tempered bar did not machine as well, while the annealed bar machined the poorest. All three of these bars appeared rather tough to machine in comparison to the SAE.3250 and SAE.4350 steel bars. All the gear blanks from the 6150 steel bars were too hot to hold in the hand, indicating much friction heat developed. None of the tools after the machining of each of the nine bars for one continuous hour showed sufficient wear to necessitate regrinding or redressing.

Some experiments were then carried out in order to determine the effect of increased spindle speed on the machinability rating. Increasing the spindle speed to 418 r.p.m. to produce 16 instead of 12 gear blanks per hour showed that SAE.4350 in the quenched and tempered condition had the highest rating. Further experiments were then carried out at an increased spindle speed to produce 20 blanks per hour, and the general conclusions were that for the SAE.3250 and the SAE.4350 steels the fine, close-grained spheroidised structure obtained by quenching and tempering was best for the automatic machining ; while for the SAE.6150 steel the coarse, open-grained spheroidised structure, obtained by a long anneal near the lower critical temperature, was best. The annealed (laminated-pearlitic) structure gave a poorer finish and machined harder and tougher. The quenched and tempered SAE.4350 steel bar had the highest machinability rating of the nine bars.

BROACHING The gear blanks were then rough broached by placing two blanks back to back. Carbon tetrachloride was used as the lubricant.

FACING The next operation was to face the bevels of the blanks using a single point high speed steel tool employing as a lubricant a mixture of one-third Quaker-Kut 26 and two-thirds Eccol-Kut 1-X.

GEAR CUTTING The rough and finish gear cutting was done on a 12 in. Gleason gear cutter using a sulphur base mineral oil as the lubricant. The speed was set for 23 seconds per tooth which was slightly higher than the standard rate. This produced 11 gear blanks per hour.

DISTORTION The gears were hardened and tempered to a Rockwell hardness of C48/52 to determine the variation in distortion. They were all heated slowly up to the hardening temperature, held ten minutes and oil quenched. They were then tempered for one hour. The temperatures employed were :—

Steel	*Hardening*	*Tempering*
SAE.3250	790°C.	300°C.
SAE.4350	840°C.	290°C.
SAE.6150	870°C.	200°C.

Careful examination showed that the distortion of the bores of the nine lots of steel gears was about the same. The spheroidised steel gears showed less distortion than the annealed gears or the quenched and tempered gears. The quenched and tempered gears showed slightly less distortion than the annealed gears.

The results of the machining tests can be summarised by stating that the structures which gave the best results were as follows :—

Operation	*Type of Steel*		
	SAE.3250	*SAE.4350*	*SAE.6150*
Automatic machining	Q	Q	S
Broaching	A	A	A
Gear cutting	A	A	A
Single point turning of bevel face	A	A	A

TABLE 2

Condition of Machined Surfaces

Steel SAE. No.	*Condition of Steel*	*Type of Machining*					
		Automatic Machining		*Broaching*	*Facing*	*Gear Cutting*	
		Forming	*Counterboring*			*Roughing*	*Finishing*
3250	A	Fair	Fair.	Very good.	Very good, smooth surface.	Excellent, clean, no burrs.	Good.
	S	Good.	Good.	Good.	Poor, ragged edges.	Poor, rough, heavy burrs.	Poor.
	Q	Good.	Good.	Good, slight tears on surface.	Good, slightly ragged edges.	Fair, light burrs.	Poor.

TABLE 2.—(*cont.*)

Steel SAE. No.	*Condition of Steel*	*Type of Machining*					
		Automatic Machining		*Broaching*	*Facing*	*Gear Cutting*	
		Forming	*Counterboring*			*Roughing*	*Finishing*
4350	A	Very poor.	Good.	Good.	Fair.	Fair, very light burrs	Good.
	S	Fair.	Good.	Fair, slight tears on surface.	Fair, scratched finish.	Poor, heavy burrs.	Poor.
	Q	Fair.	Fair.	Good, slight tears.	Fair, slightly rough edges.	Fair, light burrs.	Poor.
6150	A	Poor.	Fair.	Fair.	Good.	Poor, light burrs.	Fair.
	S	Fair.	Fair.	Fair, slight tears on surface.	Poor, rough edges.	Poor, heavy burrs.	Poor.
	Q	Fair.	Fair.	Fair.	Very poor, hard torn surfaces.	Very poor, heavy burrs.	Very poor.

APPENDIX 2

British and U.S. Alloy Steels

As there are numerous references in the technical press to S.A.E., N.E. and En steels without details always being given of the chemical composition, Tables 3, 4 and 5 have been included.

Table 3 gives average chemical compositions of the American S.A.E. and N.E. steels by groups and also, as a matter of interest, the dates of introduction and withdrawal of the N.E. steels which were originally produced as a war emergency measure. In actual use the last two digits refer to the average carbon content. Thus SAE.2330 contains 0.30% carbon.

Table 4 correlates the tensile properties of the En steels with the maximum allowable diameter or ruling section, and Table 5 gives average chemical compositions of the En constructional steels.

TABLE 3

Details of S.A.E. and N.E. Constructional Alloy Steels

Group No.	*Average Chemical Composition per cent.*				*Date of N.E. Steel when :—*		*Steels in SAE List in:*	
	Mn	*Ni*	*Cr*	*Mo*	*Introduced*	*Withdrawn*	*1939*	*1948*
SAE.1300	1.75	—	—	—			X	X
,, 2000	0.45	0.5	—	—			X	
,, 2100	0.45	1.5	—	—			X	
,, 2300	0.5/0.8	3.50	—	—			X	X
,, 2500	0.5	5.0	—	—			X	X
,, 3100	0.5/0.8	1.25	0.65/0.80	—			X	X
,, 3200	0.45	1.75	1.1	—			X	
,, 3300	0.5	3.50	1.60	—			X	X
,, 3400	0.45	3.0	0.8				X	
,, 4000	0.8/0.9	—	—	0.25				X
,, 4100*	0.8/0.9	—	0.5/1.0	0.25/0.20			X	X
,, 4300	0.55/0.7	1.8	0.5/0.8	0.25			X	X
,, 4600†	0.55/0.8	1.8	—	0.25			X	X
,, 4800	0.5/0.6	3.5	—	0.25			X	X
,, 5000	0.8	—	0.65/0.25	—				X
,, 5100	0.7/0.8	—	0.8/1.0	—			X	X
,, 50100	0.35	—	0.5	—				X
,, 51100	0.35	—	1.0	—				X
,, 52100	0.35	—	1.45	—			X	X

TABLE 3—(*cont.*)

Group No.	*Average Chemical Composition per cent.*				*Date of N.E. Steel when :—*		*Steels in SAE List in:*	
	Mn	*Ni*	*Cr*	*Mo*	*Introduced*	*Withdrawn*	*1939*	*1948*
,, 6100	0.8	—	1.0	(V 0.15 min.)			X	X
NE. 8000	1.15			0.15	Jan., 1942	Aug., 1943		
NE. 8100 to 8500 inclusive	1.45			0.15/ 0.50	Jan., 1942	Aug., 1943		
NE. 8600	0.80	0.55	0.50	0.20	Jan., 1942	Aug., 1943		X
,, 8700	0.80	0.55	0.50	0.25	Jan., 1942 & May, 1944	Dec., 1942‡		X
,, 8800	0.80	0.50	0.50	0.35	Jan., 1942	Sept., 1942		
,, 8900	1.15	0.50	0.50	0.35	,,	Dec., 1942		
SAE. 9200	0.65/ 0.85	—	0.0/ 0.65	(Si 1.4/ 2.0)			X	X
,, 9300	0.55	3.25	1.20	0.12				X
NE. 9400	1.10	0.45	0.40	0.12	Sept., 1942	Prior to May, 1944		X
,, 9500	1.35§	0.55	0.50	0.20	,,	,,		
,, 9600	1.50	—	0.50	(Si 0.5)	,,	Aug., 1943		
,, 9700	0.65	0.55	0.17	0.20	May, 1944			X
,, 9800	0.80	1.0	0.80	0.25	,,			X
,, 9900	0.60	1.15	0.50	0.25	,,			

* 4130 contains 0.5%–Mn. (in Group 4100)

† 4608 contains 0.45% max. Mn, 1.6%–Ni and 0.2%–Mo. (in Group 4600)

‡ Except 8720 but group reinstated May, 1944. (in Group 4700)

§ Si–0.50%.

N.B.—(*a*) SAE. 1300, 52100 and 9200 series were added to the N.E. steels from Sept., 1942 to Jan., 1945.

(*b*) The nickel range of all nickel-bearing N.E. steels was altered in Dec., 1942 from 0.4/0.6 to 0.4/0.7%.

(*c*) X signifies steel is in S.A.E. List.

TABLE 4—*B.S.970 SCHEDULE—Hardened and Tempered En Alloy Steels to Produce a Tensile Strength of 40 to 100 tons per sq. in. up to 6 in. Ruling Section in the Form of Bars, Billets, Light Forgings and Stampings*

Tensile Range		*Limits of Thickness or Ruling Section*				
Symbol	*Tons/sq. in.*	*Up to $\frac{7}{8}$" En. No.*	*$\frac{7}{8}$" to $1\frac{1}{8}$" En. No.*	*$1\frac{1}{8}$" to $2\frac{1}{2}$" En. No.*	*$2\frac{1}{2}$" to 4" En. No.*	*4" to 6" En. No.*
Q	40–50	12	12	12	12	12
		13	13	13	13	13
		14A	14A	14A	14A	
		14B	14B	14B	14B	
		15	15	15	15	
R	45–55	14A	14A	14B	16	16
		14B	14B	15	17	17
		15	15	16	18	19
		16	16	17	19	19A
		17	17	18	19A	29
		18	18	19	21	100
		19	19	19A	29	110
		19A	19A	21	100	111
		21	21	29	110	160
		29	29	100	111	
		100	100	110	160	
		110	110	111		
		111	111	160		
		160	160			
S	50–60	15	16	16	16	17
		16	17	17	17	23
		17	18	18	19	24
		18	19	19	19A	29
		19	19A	19A	22	110
		19A	21	21	23	
		21	22	22	24	
		22	23	23	29	
		23	24	24	100	
		24	29	29	110	
		29	100	100	111	
		100	110	110	160	
		110	111	111		
		111	160	160		
		160				
T	55–65	16	16	16	17	23
		17	17	17	23	24
		18	18	19	24	25
		19	19	19A	25	27
		19A	19A	20	27	29
		20	20	22	29	
		22	22	23	110	
		23	23	24		
		24	24	25		
		25	25	27		
		27	27	29		
		29	29	100		
		100	100	110		
		110	110	111		
		111	111	160		
		160	160			

TABLE 4 (*contd.*)

Tensile Range		*Limits of Thickness or Ruling Section*				
Symbol	*Tons/sq. in.*	*Up to $\frac{7}{8}$" En. No.*	*$\frac{7}{8}$" to $1\frac{1}{8}$" En. No.*	*$1\frac{1}{8}$" to $2\frac{1}{2}$" En. No.*	*$2\frac{1}{2}$" to 4" En. No.*	*4" to 6" En. No.*
U	60–70	16	16	17	23	23
		17	17	19	24	25
		19	19	23	25	26
		19A	19A	24	26	27
		23	23	25	27	28
		24	24	26	28	29
		25	25	27	29	
		26	26	28		
		27	27	29		
		28	28	110		
		29	29			
		100	100			
		110	110			
		111	111			
		160	160			
V	65–75	16	17	23	25	25
		17	19	24	26	26
		19	20	25	27	27
		19A	23	26	28	28
		20	24	27	29	
		23	25	28		
		24	26	29		
		25	27			
		26	28			
		27	29			
		28	100			
		29	110			
		100				
		110				
W	70–80	19	19	25	25	26
		24	24	26	26	
		25	25	27	27	
		26	26	28	28	
		27	27	29	29	
		28	28			
		29	29			
		110	110			
X	75–85	24	24	25	26	26
Y	80–90	25	25	26		
		26	26	28		
		28	28			
Z	100 min.	24	24	25	26	
		25	25	26	30A*	30A*
		26	26	29*	30B*	30B*
		29*	29*	30A		
		30A	30A	30B		
		30B	30B			

* If oil quenched.

TABLE 5

Average Chemical Compositions of B.S.970 En Constructional Alloy Steels

En. No.	*Type*	*Chemical Composition per cent.*					*Specified Core Properties (minimum)*	
		C.	*Mn.*	*Ni.*	*Cr.*	*Mo.*	*Max. Stress t.s.i.*	*Izod Impact ft. lb.*
	Case-Hardening Steels							
33	3% nickel	0.13	0.45	3.25	0.3*	—	45	40 on 1½″ dia. bar
34	2% nickel-molybdenum (lower c)	0.17	0.45	1.75	—	0.25	45	40 do.
35	2% nickel-molybdenum (higher c)	0.24	0.45	1.75	—	0.25	55	25 do.
36	3% nickel-chromium ...	0.15	0.45	3.5	0.8	—	55	35 do.
							65	30 do.
37	5% nickel	0.13	0.3	5.0	0.3*	—	40	50 do.
38	do.	0.13	0.45	5.0	0.3*	0.2†	65	30 do.
39A	4¼% nickel-chromium ...	0.15	0.35	4.2	1.2	—	85	25 do. ‡
39B	4¼% nickel-chromium-molybdenum ...	0.15	0.35	4.2	1.2	0.25	85	25 do. ‡
201	Carbon-Manganese ...	0.15	1.25	—	—	—	40	40 do.
202	do. (free-machining)	0.15	1.25	—	—	—	38	30 do.
206	Low-chromium ..	0.15	0.4	—	0.4	—	not specified	
207	do. ...	0.19	0.7	—	0.7	—		
320	2% nickel-chromium-molybdenum ...	0.17	0.55	2.0	2.0	0.2	85	25 do.
325	Low nickel-chromium-molybdenum ...	0.20	0.55	1.75	0.5	0.25	55	35 do.
	Nitriding Steels							
40A	3% chromium-molybdenum	0.15	0.5	0.4*	3.2	0.55	45	40 for 6″ limiting ruling section
40B	do.	0.25	0.5	0.4*	3.2	0.55	50	40 do.
							55	40 do.
							60	35 for 4″ limiting ruling section
40C	do. (higher tensile)	0.4	0.6	0.4*	3.0	1.0§	‖	‖
41	1½% chromium-aluminium-molybdenum	0.45*	0.5	0.4*	1.6	0.2¶	35	45 up to 2½″ limiting ruling section
							45	40 do.
							55	35 do.

TABLE 5—(*cont.*)

En. No.	*Type*	*Chemical Composition per cent.*				
		C.	*Mn.*	*Ni.*	*Cr.*	*Mo.*
	Direct-Hardening Steels					
12	1% nickel	0.40	1.0	1.0	—	—
13	Manganese-nickel-molybdenum ...	0.20	1.6	0.6	—	0.25
14A	Carbon-manganese	0.20	1.5	0.4*	0.25*	—
14B	do.	0.25	1.5	0.4*	—	—
15	do. (higher tensile)	0.35	1.5	—	—	—
16	Manganese-molybdenum	0.30	1.5	—	—	0.3
17	do. (higher molybdenum)	0.35	1.5	—	—	0.45
18	1% chromium	0.40	0.8	—	1.0	—
19	1% chromium molybdenum ...	0.40	0.65	—	1.2	0.30
19A, B & C	do. ...	0.40	0.65	—	1.0	0.25
20	do. (higher molybdenum)	0.50*	0.55	0.3*	1.0	1.0*
21	3% nickel	0.30	0.55	3.25	0.3*	—
22	3½% nickel	0.40	0.65	3.50	0.3*	—
23	3% nickel-chromium	0.30	0.55	3.20	0.75	0.25†
24	1½% nickel-chromium-molybdenum	0.40	0.55	1.50	1.20	0.25
25	2½% nickel-chromium-molybdenum (medium carbon)	0.30	0.60	2.50	0.65	0.55
26	2½% nickel-chromium-molybdenum (high carbon)	0.40	0.60	2.50	0.65	0.55
27	3% nickel-chromium-molybdenum	0.30	0.50	3.50	0.90	0.40
28	3½% nickel-chromium-molybdenum	0.33	0.50	3.75	1.20	0.40
29	3% chromium-molybdenum ...	0.25	0.50	0.4*	3.0	0.50
30A	4½% nickel-chromium	0.30	0.50	4.25	1.25	—
30B	4½% nickel-chromium-molybdenum	0.30	0.50	4.25	1.25	0.30
31	1% carbon-chromium	1.0	0.50	—	1.30	—

* Maximum.
† Optional.
‡ On test-piece size.
§ Vanadium 0.15%.
‖ Mechanical properties to be agreed between purchaser and manufacturer.
¶ Aluminium 1.1%.

N.B.—The tensile ranges of the direct-hardening steels are shown in TABLE 4.

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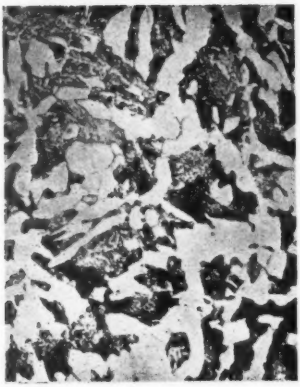
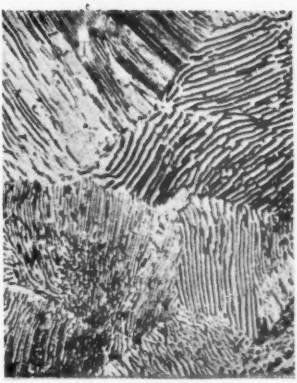
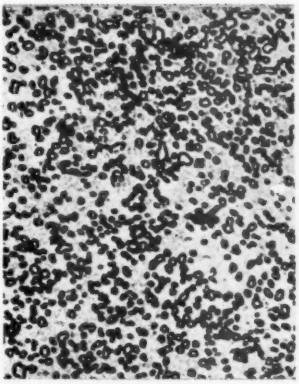


A.



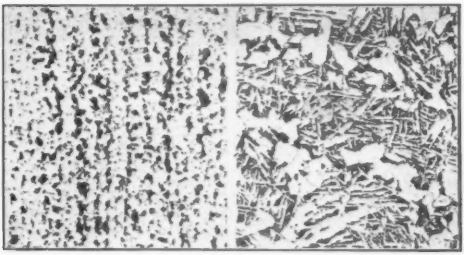
B.

C.



D.

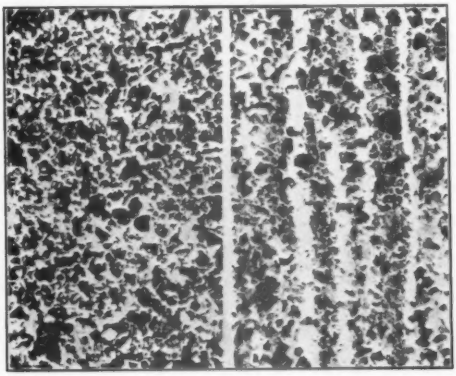
FIG. 1. Showing types of micro-structure of steel encountered in machining :— A. Low carbon steel in the normalised condition showing ferrite (white) and pearlite (dark). B. Lamellar pearlite. C. Spheroidised. D. Sorbitic. (Magnification × 750.)



A. B.

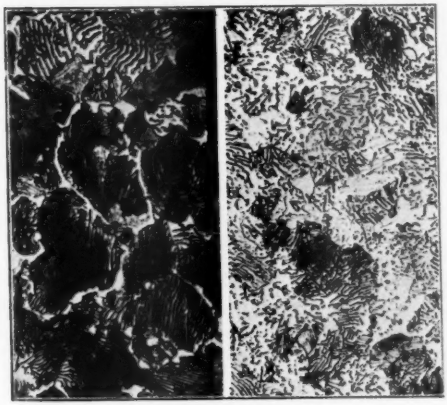
FIG. 2. Showing the effect of structure on the machinability of 2 per cent. nickel-molybdenum case-hardening steel (SAE.4615 or En.34) in the form of tubing. A. is a fine banded structure of ferrite and pearlite and gave at a Brinell hardness of 165-187, a production rate of 19.5 per hour. The coarse structure B. obtained by a high temperature normalising operation gave a Brinell hardness of 156-170 and a production rate of 30-38 per hour. (Magnification × 100).

Courtesy of The American Society for Metals.



A. B.

FIG. 3. Good and poor machining structures of 1 per cent. chromium steel (carbon 0.30-0.35 per cent.) The normalised structure in A. gave good machining whereas the banded structure in B. was undesirable. (Magnification × 100.) *Courtesy of The American Society for Metals.*



A. B.

FIG. 4. Good and poor machining structures in 1¼ per cent. nickel-chromium gear steel SAE.3145. A. gave good machining and consisted of lamellar pearlite and a little free ferrite, whereas B. which consisted of partially divorced and spheroidised pearlite gave poor machining. (Magnification ×750.) *Courtesy of The American Society for Metals.*

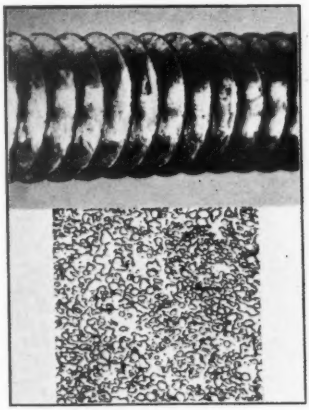


Fig. 5.

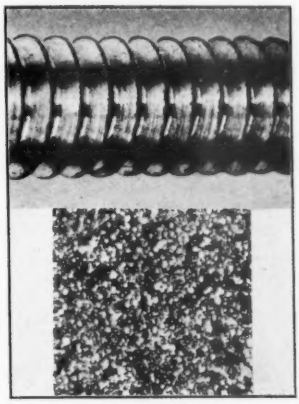
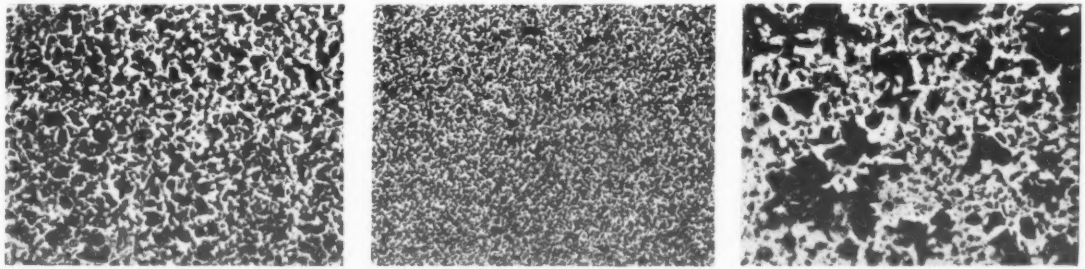


Fig. 6.

FIG. 5. Showing the torn threads of a tap blank made from carbon-vanadium tool steel and the spheroidised structure associated with them. (Magnification × 1,000.) *Courtesy of The American Society for Metals.*

FIG. 6. Showing the improvement in thread cutting (see Fig. 5) obtained by modifying the heat treatment to provide a partially sorbitic and slightly harder structure. (Magnification × 1,000.)
Courtesy of The American Society for Metals.



(A.) Desirable: normal grain. (B.) Acceptable: fine grain. (C.) Acceptable: slightly duplexed.

(D) Not acceptable: banded. (E.) Not acceptable: coarse grain. (F.) Not acceptable: spheroidised.

FIG. 7. Showing structures which are acceptable and unacceptable in the machining of 1¼ per cent. nickel-chromium steel (SAE.3135 or En.111) in the normalised and annealed condition. (Magnification × 100.)
Courtesy of the Editor of Materials and Methods.

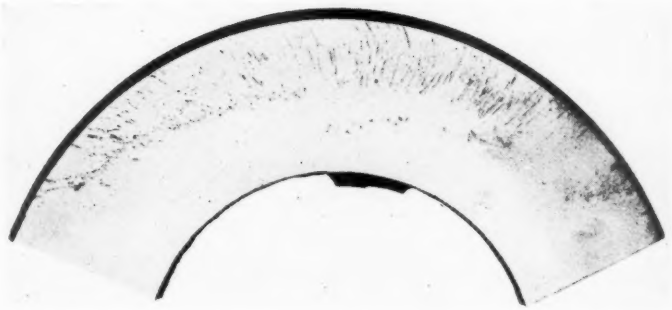


FIG. 8. Showing unusual distribution of alumina particles in an alloy steel gear blank which caused excessive tool wear.

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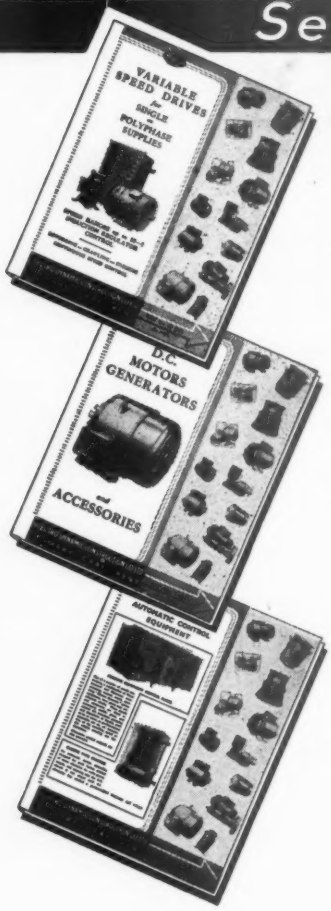
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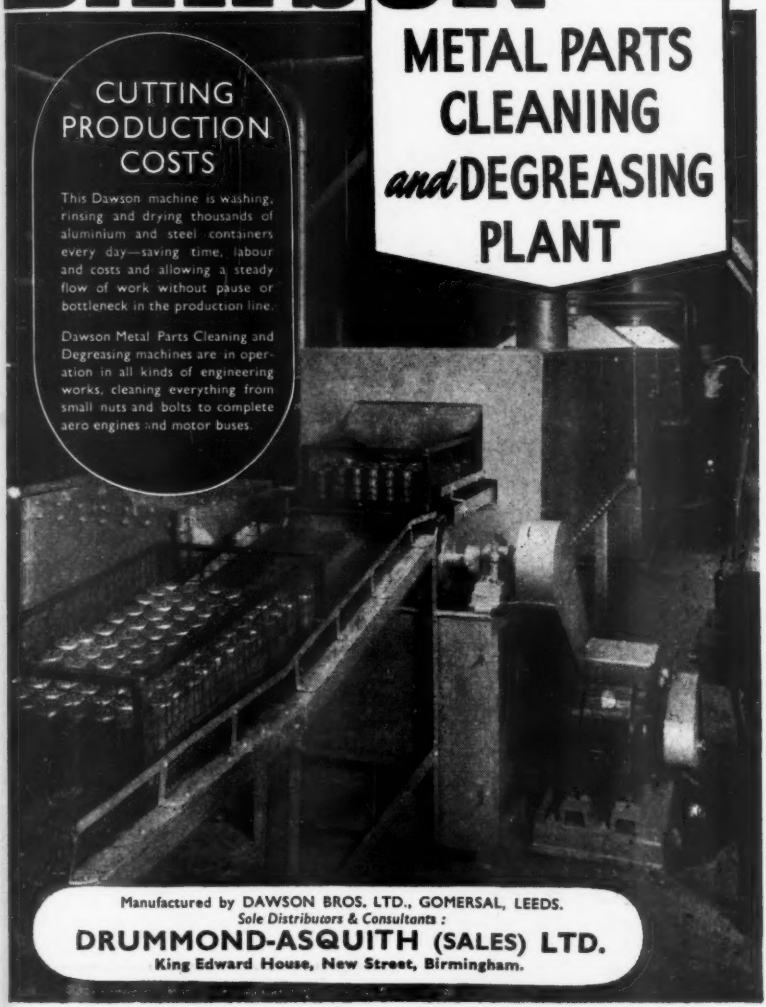

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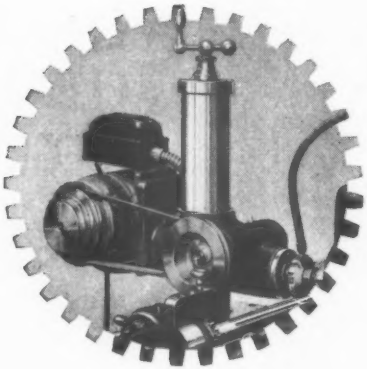

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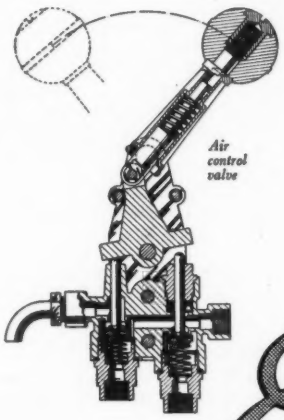

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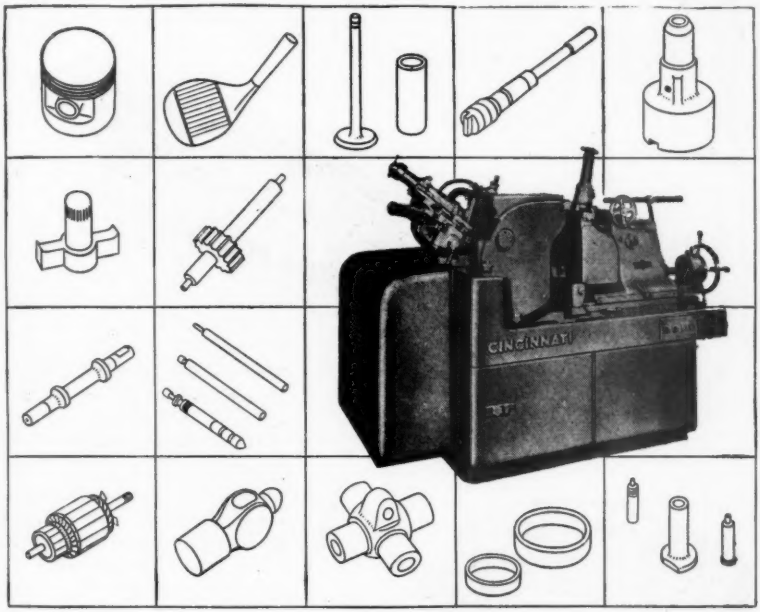

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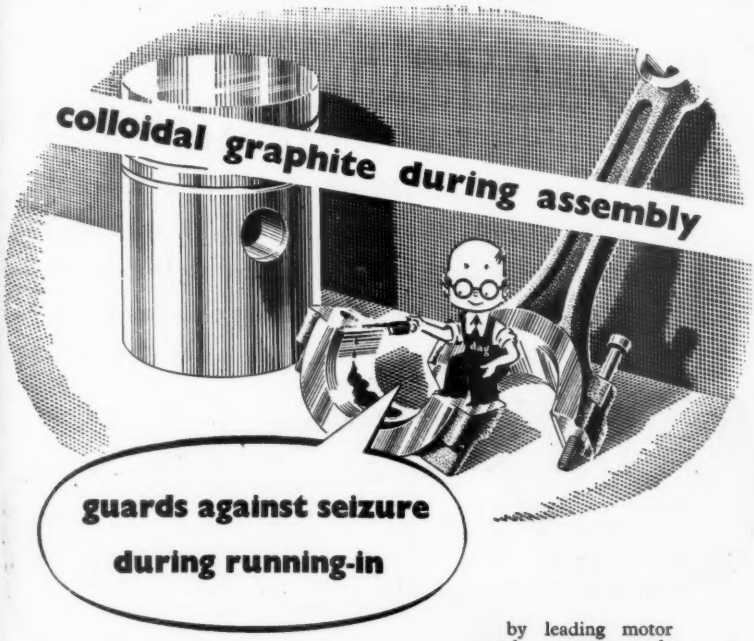

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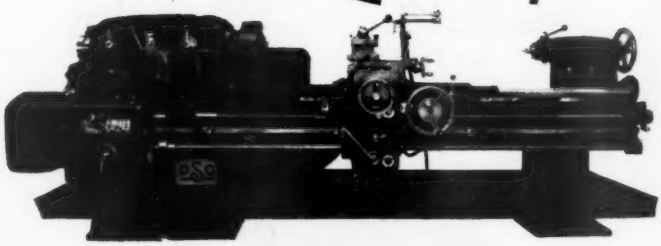

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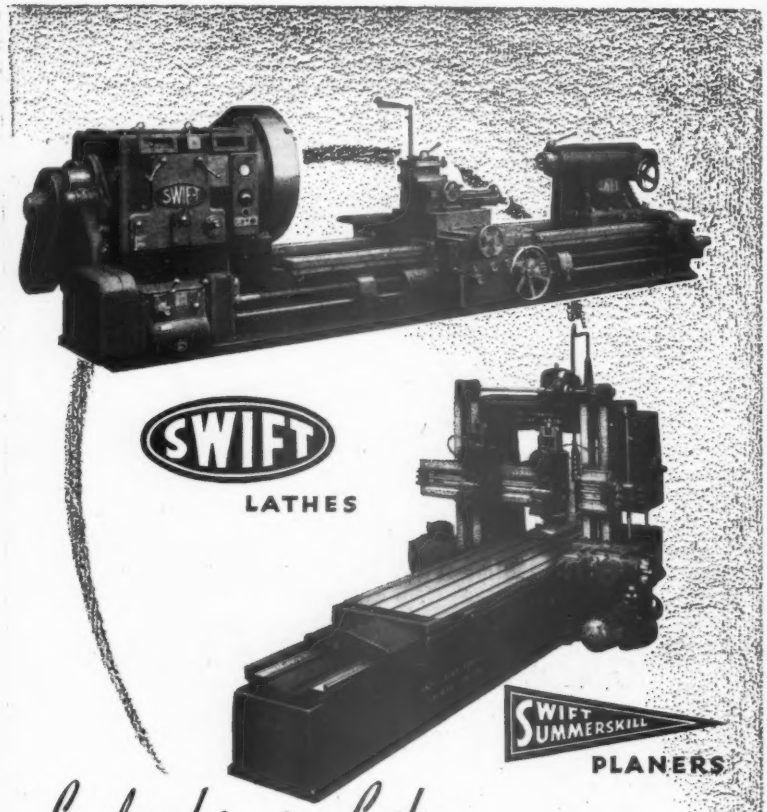

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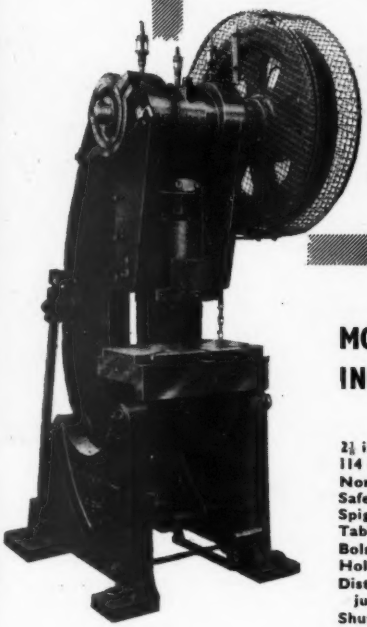

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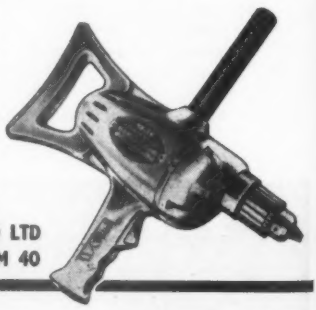

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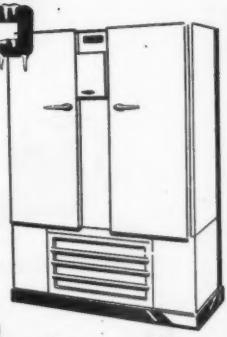

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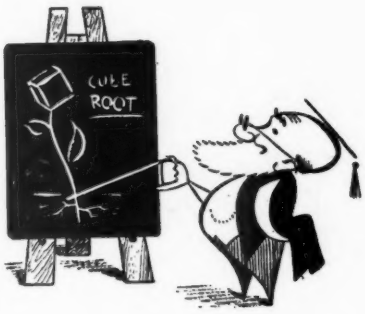

Will Might, the Mill-wright
——and the PROF.
set-too No. EIGHT

"TODAY we will devote ourselves to Mathematics. To avoid the possibility of resentment, Will Might, we will make no reference to vulgar fractions, and pass on to cube root. Now the simple root of all evil is money. We learn this from the warble-flies attached to dance bands. These warblers must not be confused with the warble-fly, grandchild of the Pupa Hypoderma Bovis, sadly referred to in my last lecture."

"Now, money, ipso facto is the root of all evil ; but let us resolve the cube-root of another representative unit, such a figure, as Will Might, say. It will be found in this case that starting with an infinitesimal amount of original evil something of considerable offense is the outcome. The basic insignificance is multiplied by itself twice over to get a result which has the crookedness value of Will *squared*, a situation with potentialities for evil . . . . . "

"That's alright, old cock. I'm willing to be squared. But it'll take more of the root-of-all-evil than you've got, Prof : "

"But let me ask you something, Prof : What is the cube root of the factor of tortional strength requisite in a Hendrys' Belt to sustain the initial tensional strain in applying momentum to a machine with a static inertia factor of x-? You don't know."

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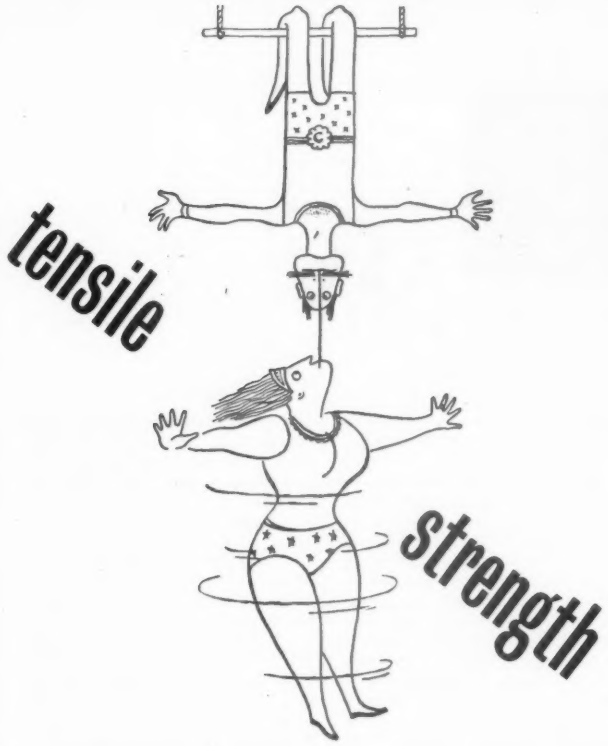

The strain on the teeth of this lady and gentleman is nothing to the strain on the teeth of many long-suffering gear-wheels.

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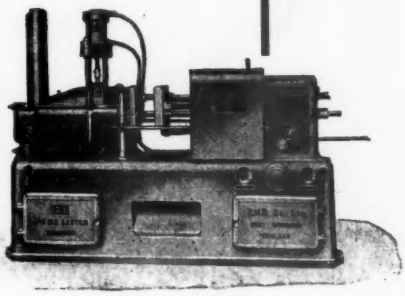

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- HIGH OUTPUT
- LARGE FURNACE CAPACITY
- SINGLE LEVER CONTROL
- INTERLOCKED SAFETY GUARD

CAPACITY

HORIZONTAL DISTANCE BETWEEN BARS ..... 8¼ in.
MAX. & MIN. DIE THICKNESS ..... 7 in. — 2 in.
MOVEMENT OF PLATEN ..... 4½ in.
WEIGHT (INCL. SPRUE) per shot ..... up to 12 ozs.
SPEED OF OPERATION ..... up to 20 shots min.

EMB

E.M.B. Co. Ltd.

WEST BROMWICH——————ENGLAND

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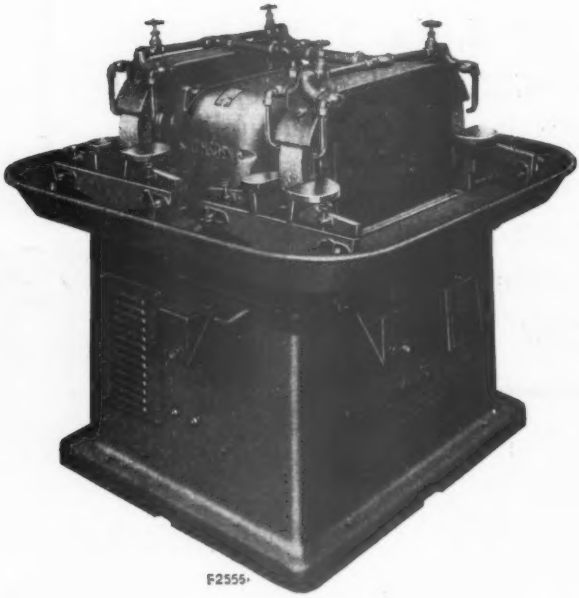

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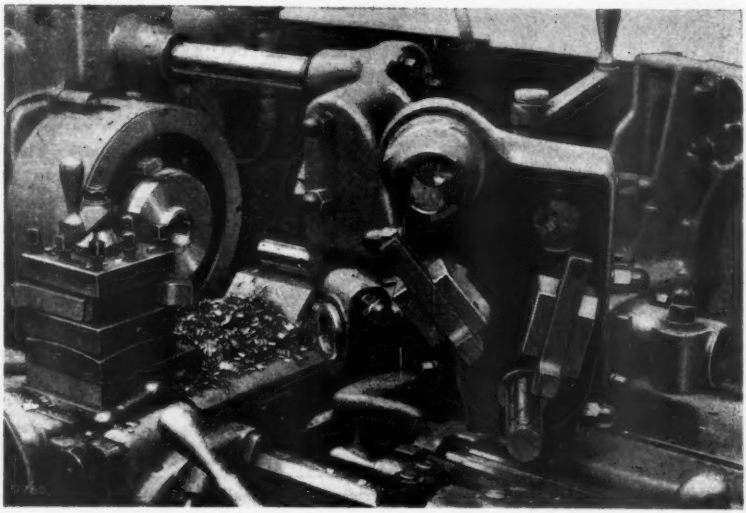

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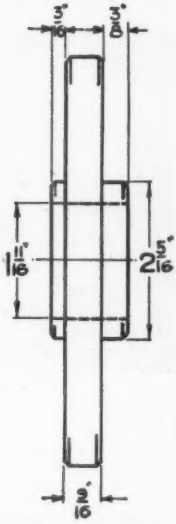

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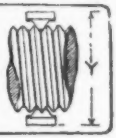

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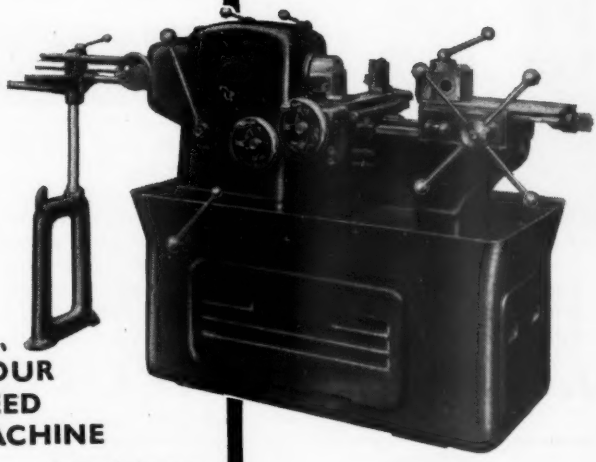
diameter.



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THE NEED
THE MACHINE

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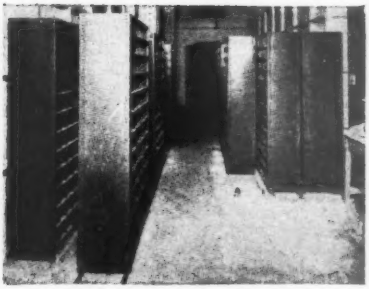

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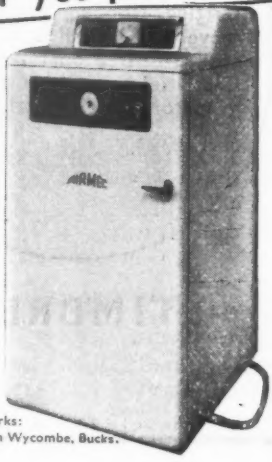

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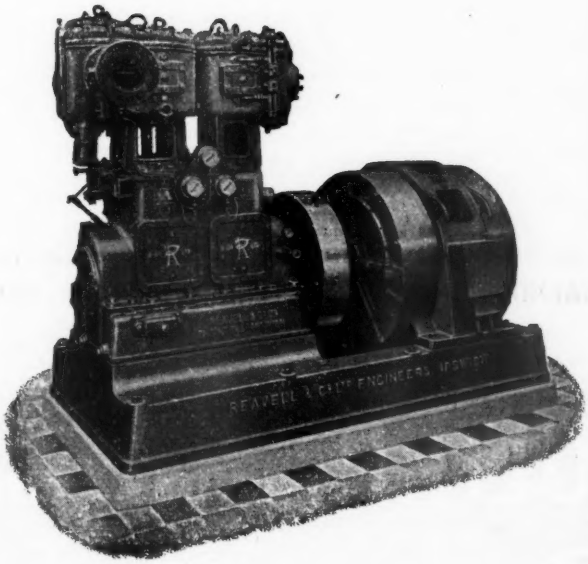

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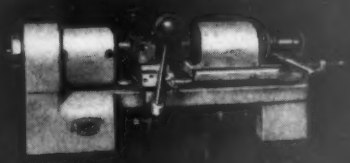

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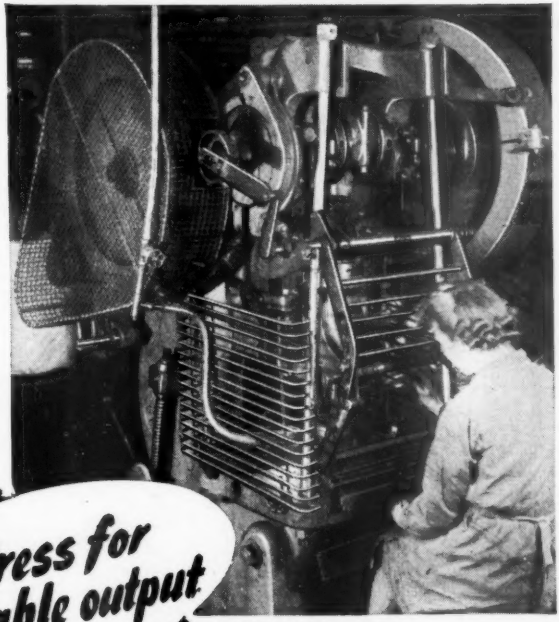

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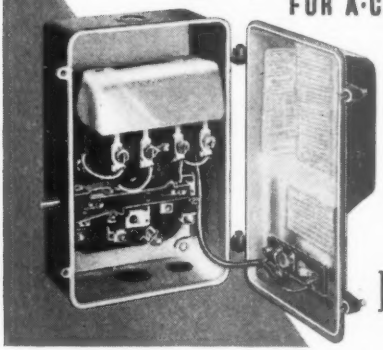

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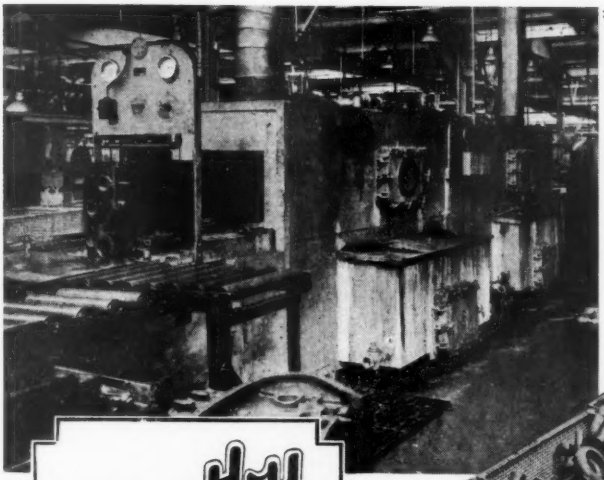

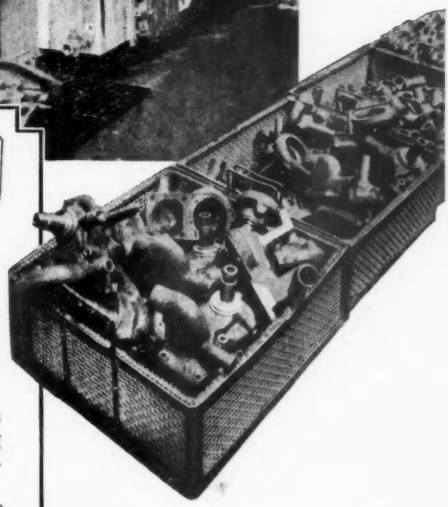

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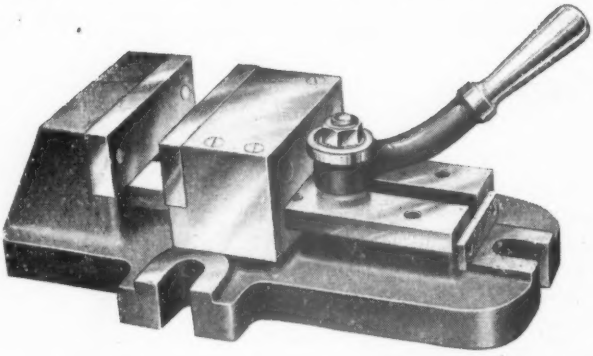

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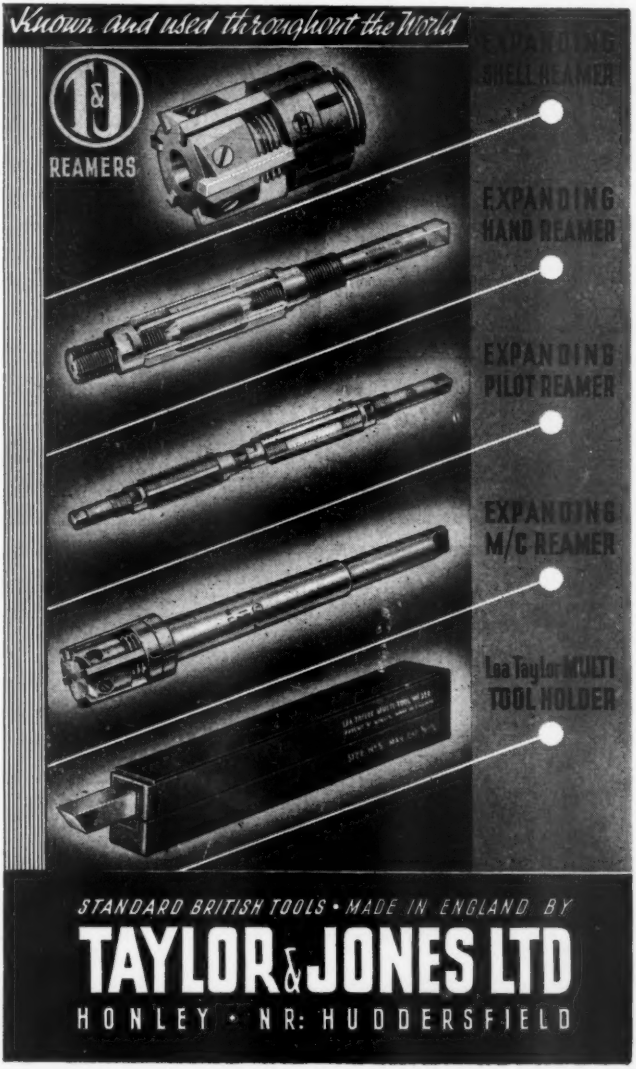
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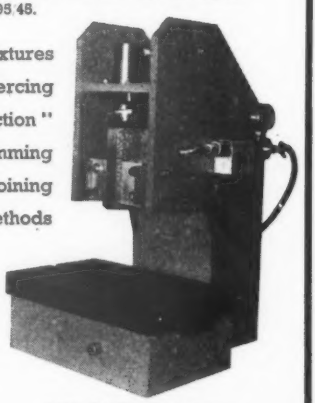

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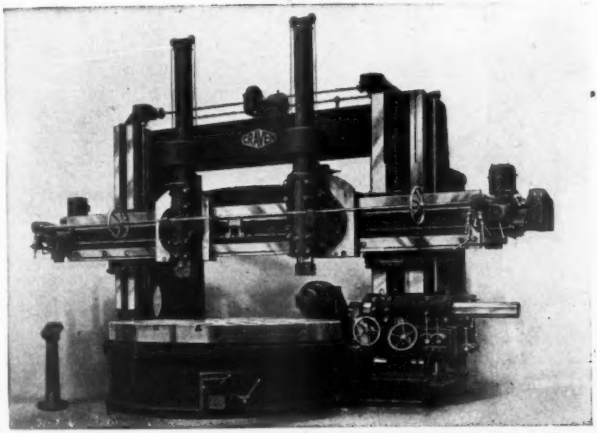

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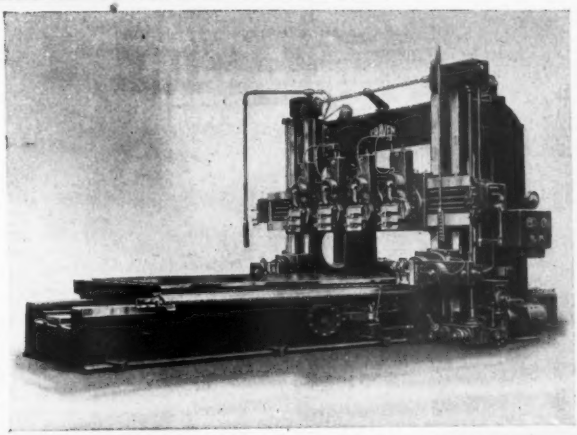

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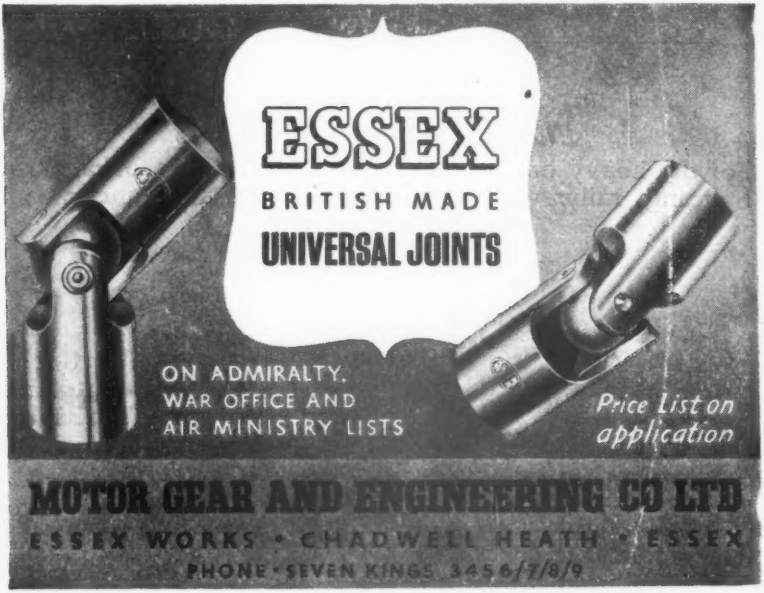
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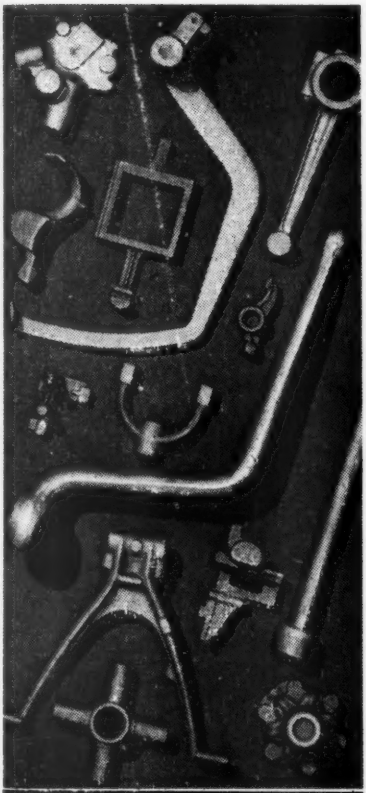

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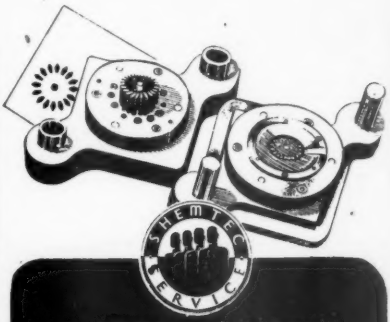

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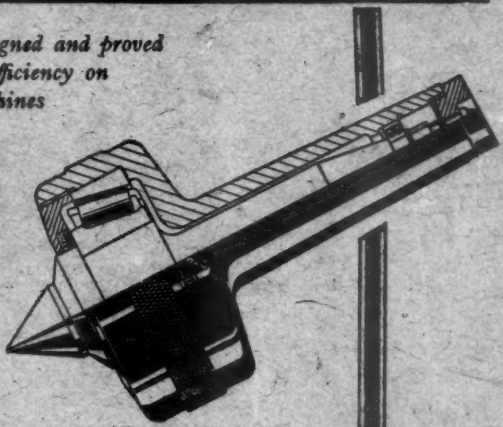

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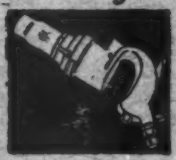

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